Feb. 6, 1951 N. C. PRICE **2,540,594**

RAM JET ENGINE HAVING VARIABLE AREA INLETS

Filed Aug. 23, 1946

8 Sheets-Sheet 1

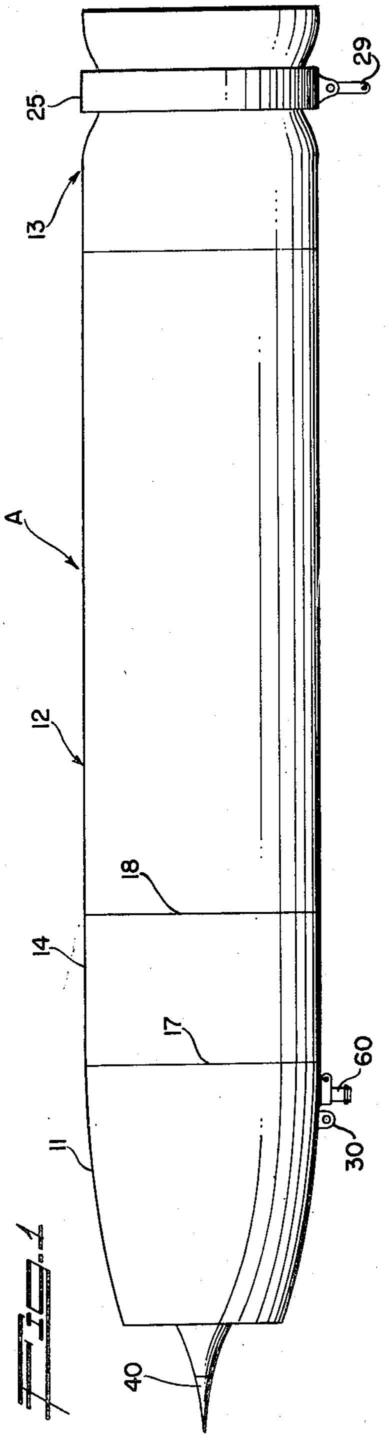


Fig. 1

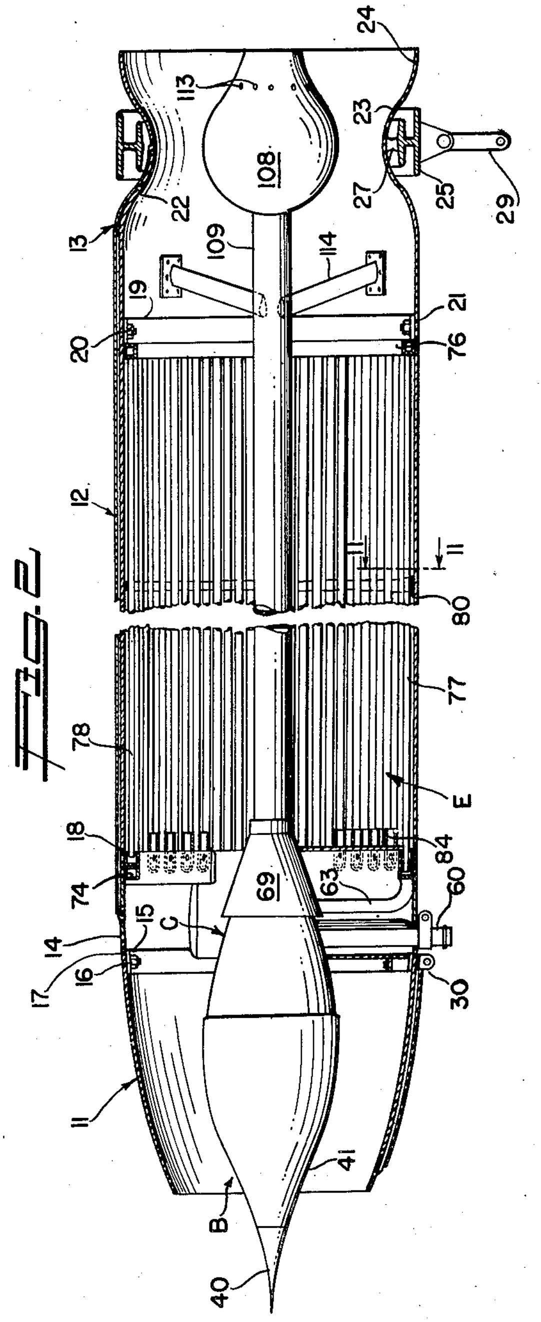


Fig. 2

INVENTOR.
NATHAN C. PRICE
BY
George C. Sullivan
Agent

Feb. 6, 1951 N. C. PRICE 2,540,594

RAM JET ENGINE HAVING VARIABLE AREA INLETS

Filed Aug. 23, 1946 8 Sheets-Sheet 2

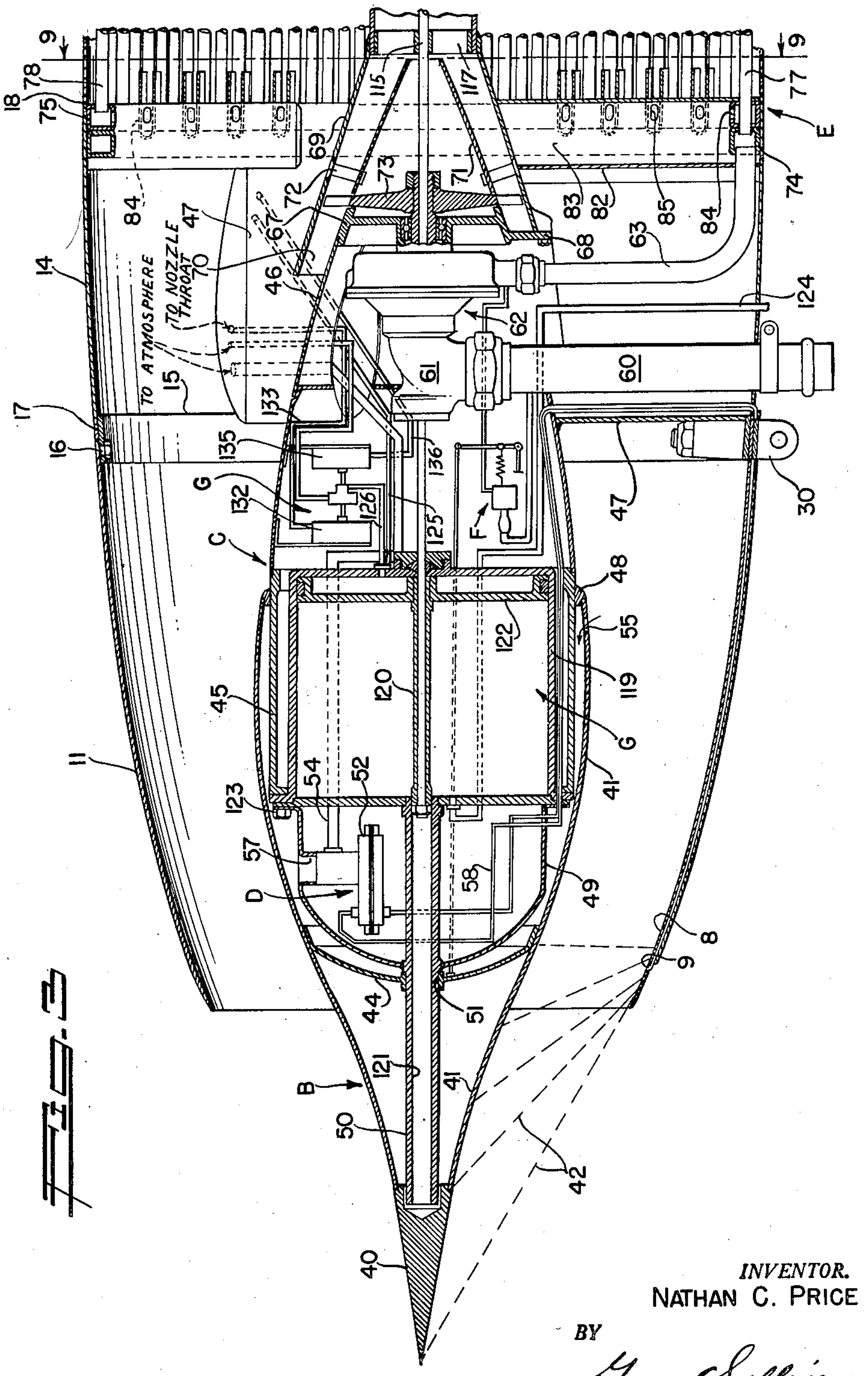


FIG. 2

INVENTOR.
NATHAN C. PRICE

BY George C. Sullivan
Agent

Feb. 6, 1951 N. C. PRICE 2,540,594

RAM JET ENGINE HAVING VARIABLE AREA INLETS

Filed Aug. 23, 1946 8 Sheets-Sheet 3

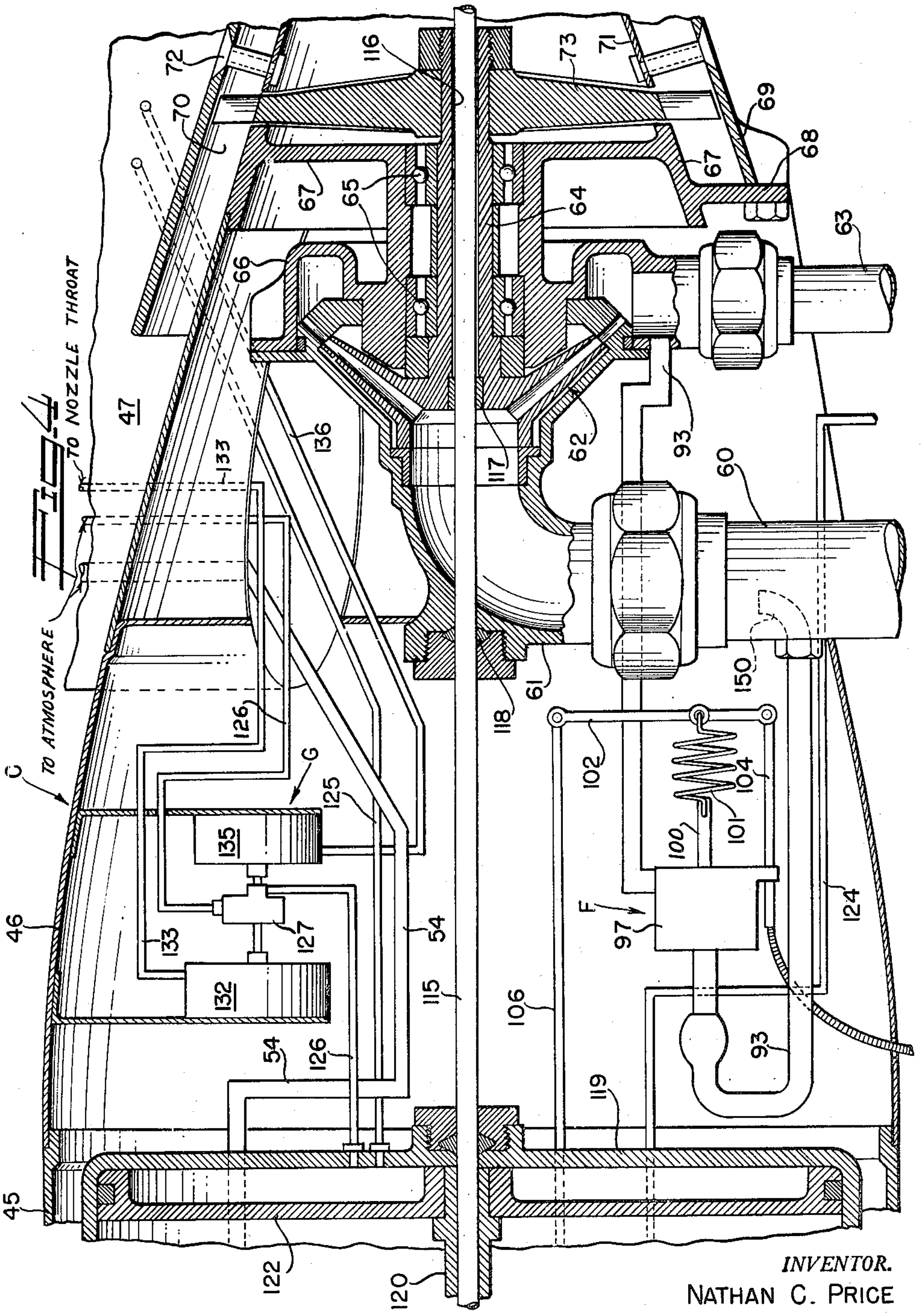


Fig-4

INVENTOR.
NATHAN C. PRICE
BY
George C. Sullivan
Agent

RAM JET ENGINE HAVING VARIABLE AREA INLETS

Filed Aug. 23, 1946

8 Sheets-Sheet 4

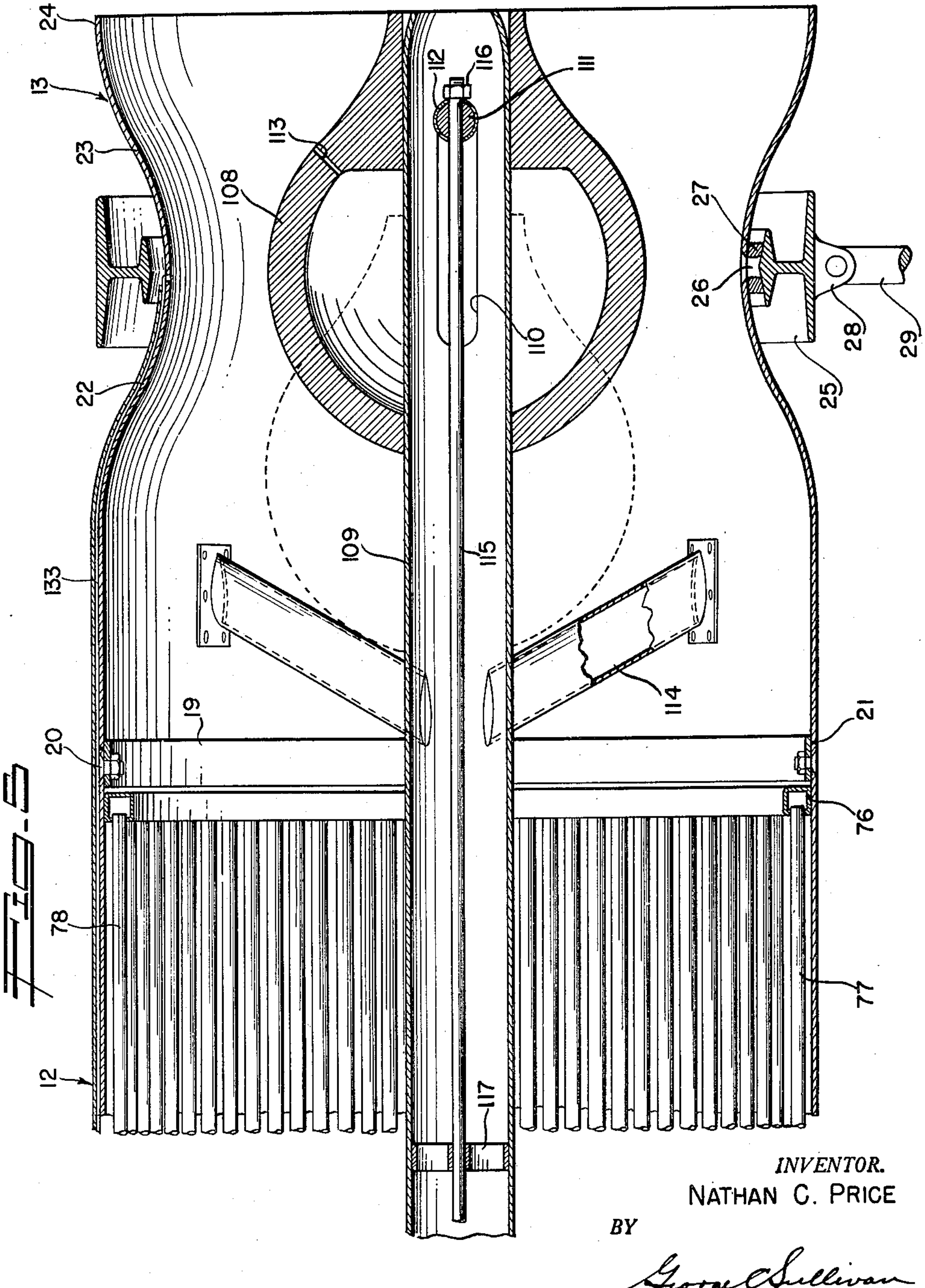


FIG-5

INVENTOR.
NATHAN C. PRICE
BY
George C. Sullivan
Agent

Feb. 6, 1951 N. C. PRICE **2,540,594**

RAM JET ENGINE HAVING VARIABLE AREA INLETS

Filed Aug. 23, 1946 8 Sheets-Sheet 5

Fig. 6

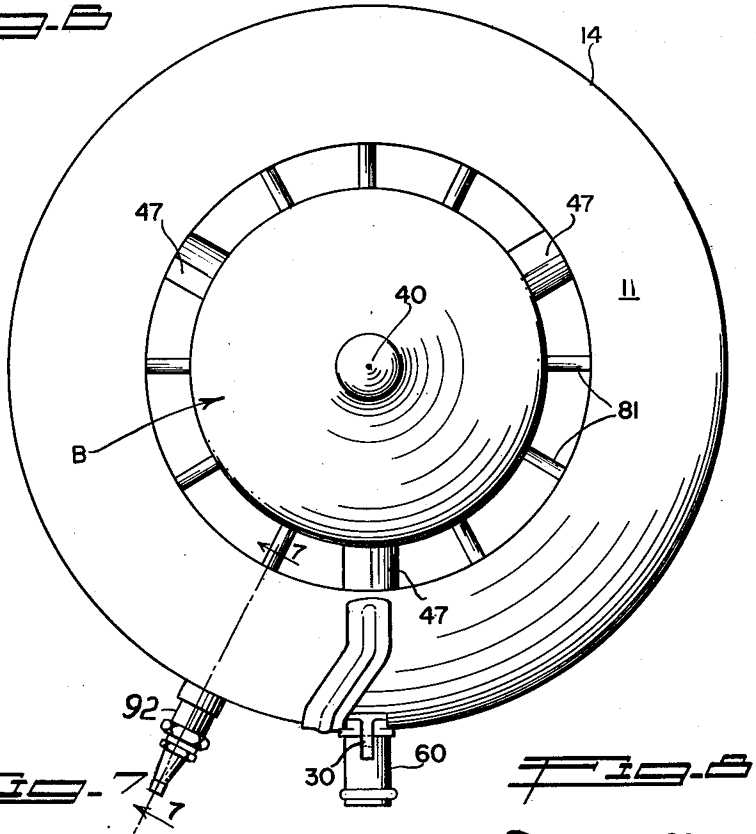


Fig. 7

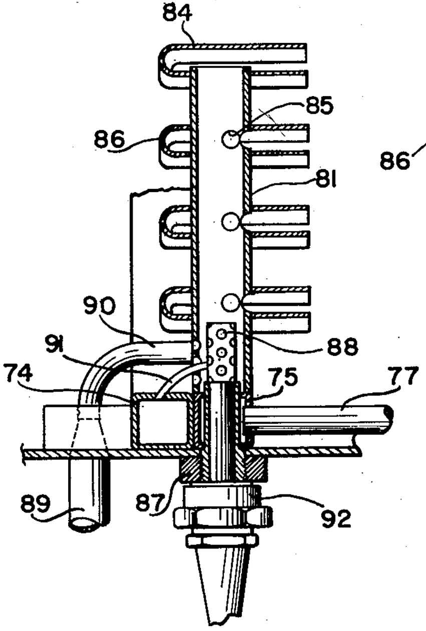
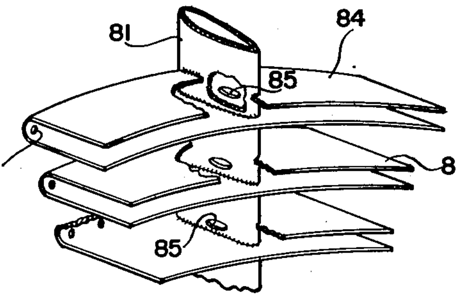


Fig. 8



INVENTOR.
NATHAN C. PRICE
BY
George C. Sullivan
Agent

Feb. 6, 1951 N. C. PRICE **2,540,594**

RAM JET ENGINE HAVING VARIABLE AREA INLETS

Filed Aug. 23, 1946 8 Sheets-Sheet 6

Fig. 9

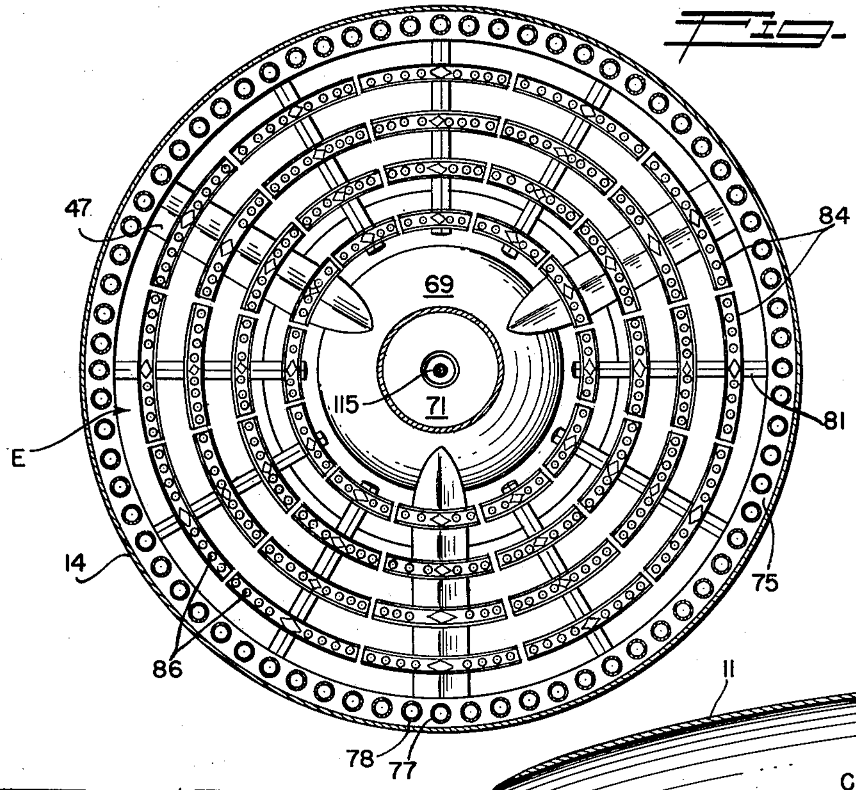


Fig. 10

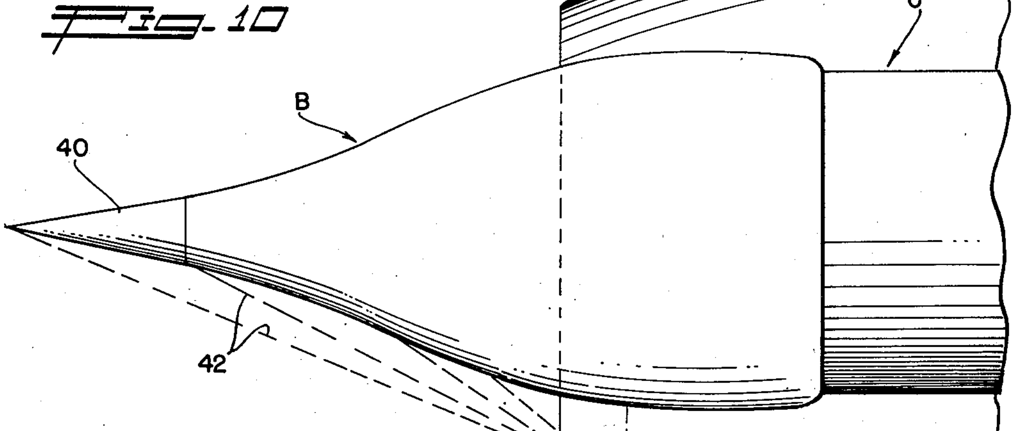
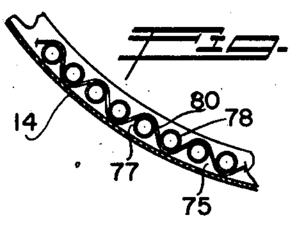


Fig. 11



INVENTOR.
NATHAN C. PRICE
BY
George A Sullivan
Agent

Feb. 6, 1951 N. C. PRICE **2,540,594**

RAM JET ENGINE HAVING VARIABLE AREA INLETS

Filed Aug. 23, 1946 8 Sheets-Sheet 7

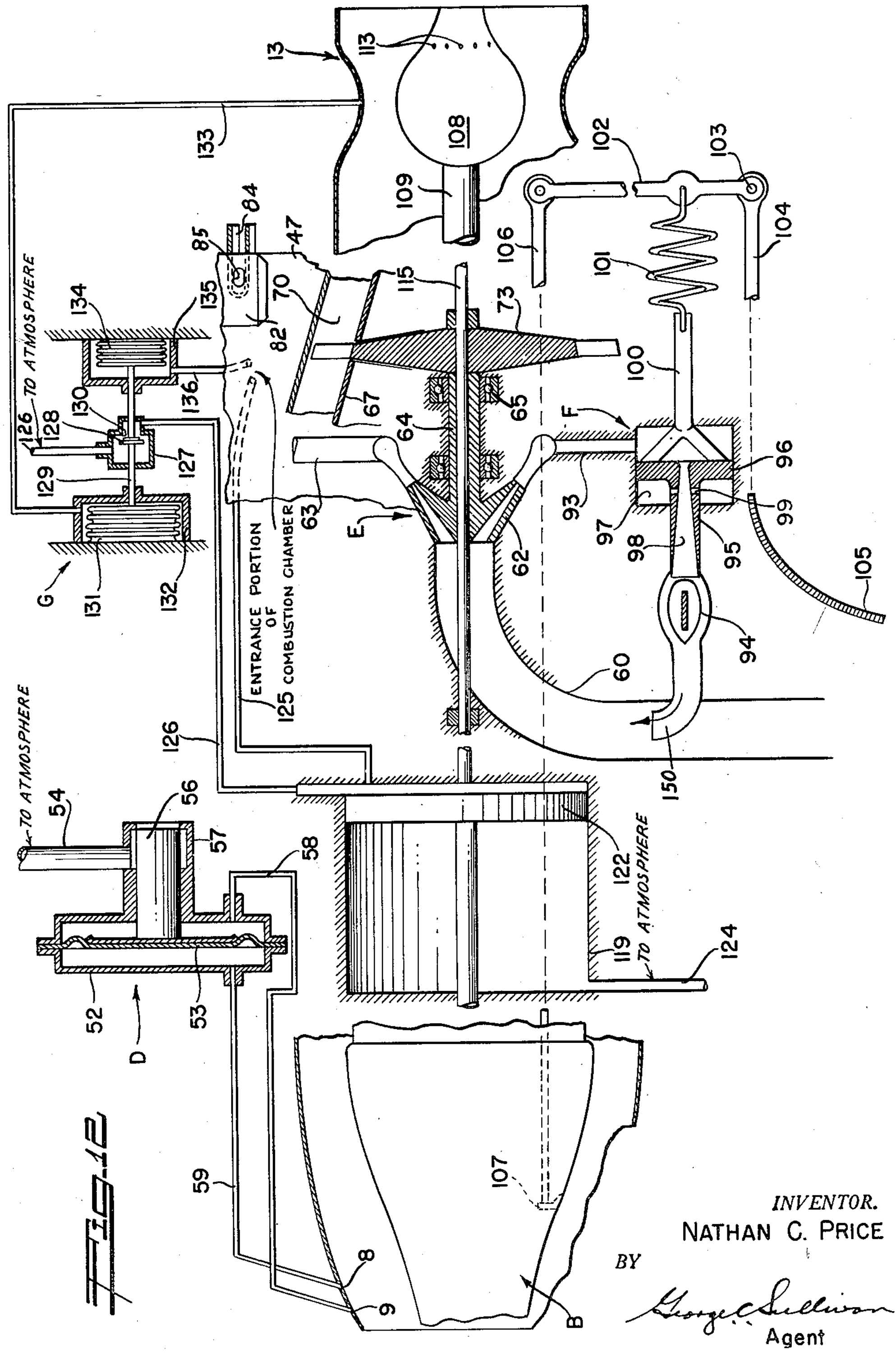


FIG. 12

INVENTOR.
NATHAN C. PRICE
BY George C. Sullivan
Agent

Fig. 13

Mach No. 1.0

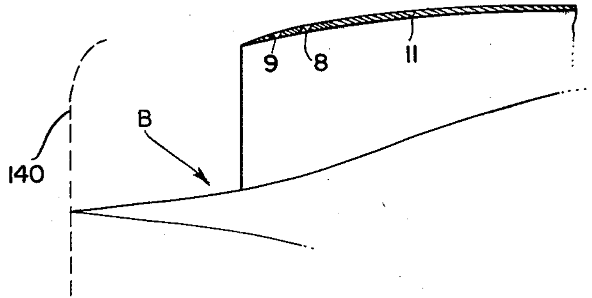


Fig. 14

Mach No. 1.4

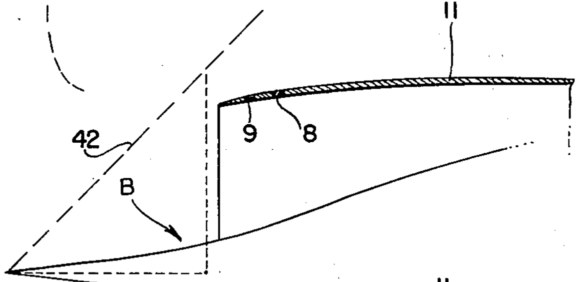


Fig. 15

Mach No. 2.0

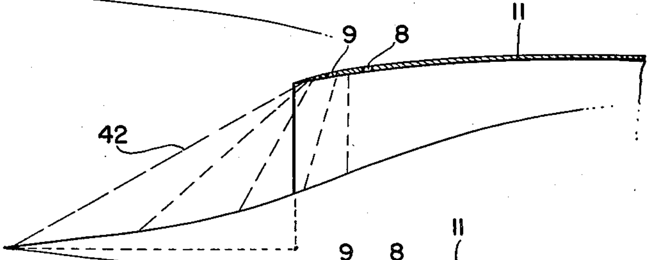


Fig. 16

Mach No. 2.5

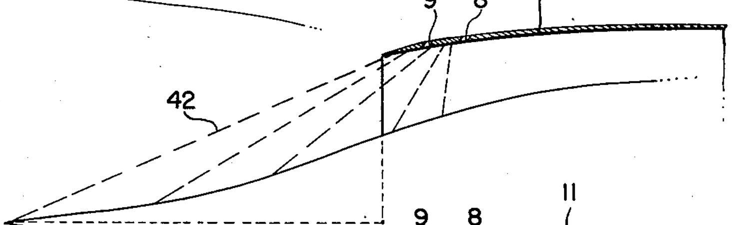
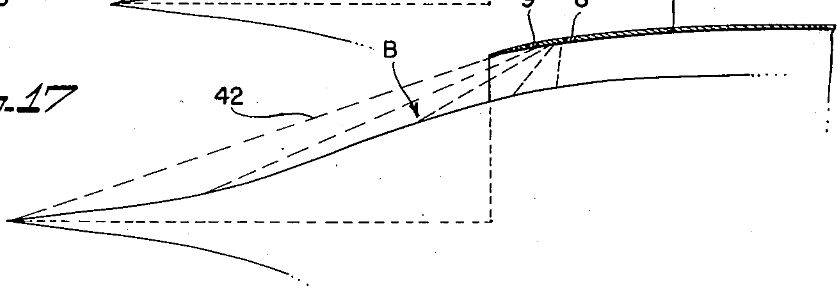


Fig. 17

Mach No. 3.0



INVENTOR.
NATHAN C. PRICE

BY

George C. Sullivan
Agent

Patented Feb. 6, 1951 **2,540,594**

UNITED STATES PATENT OFFICE

2,540,594

RAM JET ENGINE HAVING VARIABLE AREA INLETS

Nathan C. Price, Los Angeles, Calif., assignor to Lockheed Aircraft Corporation, Burbank, Calif.

Application August 23, 1946, Serial No. 692,423

30 Claims. (Cl. 60—35.6)

This invention relates to reactive propulsion engines or power plants, and relates more particularly to ram jet engines having variable area inlets useful in the propulsion of missiles and high velocity aircraft.

In the propulsion of aircraft and airborne missiles, speed and altitude are factors which limit the efficiency and practicability of reciprocating engines, and beyond certain speed and altitude limits, the efficiency of the reciprocating engine drops to the point that it is no longer practical as a means of propulsion. The turbo-jet reactive propulsion power plant is effective at velocities and altitudes beyond those obtainable with the reciprocating engine, but the turbo-jet unit also has its speed and altitude limitations. The so-called ram jet type of engine, to which the present invention relates, is practical and efficient at speeds and altitudes far above those at which either the reciprocating engine or turbo-jet unit can operate. Accordingly, the ram jet engine extends the speed and altitude capabilities of aircraft and airborne missiles.

It is an object of this invention to provide a practical effective ram jet engine embodying a variable control means operating to automatically govern the ram air inlet diffuser to obtain efficient compression at various altitudes and velocities of operation. The power plant employs an adjustable needle in the convergent-divergent inlet diffuser which is automatically moved axially in response to velocity variations to produce and utilize series of reflected shock waves of low or medium intensity to obtain a greater efficiency of compression than is possible with a single severe shock wave. The area or zone of convergence of these reflected shock waves is a region of high compressibility in the ram inlet, and the control means of the invention utilizes the position of this zone of convergence as a factor or index for determining the needle position to obtain optimum compression at various velocities. The automatic adjustment or regulation in the position of the needle affords efficient compression at different speeds in the supersonic range of flight or engine operation.

Another object of the invention is to provide a ram jet power plant characterized in part by a fuel system maintaining a substantially constant air-fuel ratio in the combustion chamber, irrespective of both the translational speed and altitude. The fuel system may employ a centrifugal pump driven by an air turbine, which in turn is driven by the rammed air column. At a Mach number of approximately 3.0, the spouting velocity of the reactive power plant is approximately twice that of the translatory velocity, bringing the point of maximum thrust into coincidence with that required for maximum range and best efficiency. To obtain fuel economy at lower Mach numbers, the fuel system is automatically controlled by a connection with the inlet diffuser needle and provision is also made to set or regu-

late the fuel system to obtain practically any required thrust at various speeds.

It is another object of the invention to provide a ram jet power plant which effects full thermal vaporization of the fuel prior to its introduction, into a constant pressure type combustion chamber, at a multiplicity of shielded injection orifices located adjacent the entrance of the combustion chamber so as to effect a uniform dispersion of the vaporized fuel across the air stream. The vaporizing and injecting means are constructed and arranged to obtain maintained flame propagation and efficient fuel combustion at the various speeds of operation.

Another object of this invention is to provide a ram jet unit of the character referred to having a nozzle throat member automatically adjusted or moved in the supersonic propulsive nozzle of the engine to control the nozzle area and thus obtain a desirable relation between the critical nozzle throat pressure and the initial combustion chamber pressure at given nozzle velocities. An automatic means moves the throat member upstream against the force of the gas pressure tending to move the member downstream and the automatic action preserves or substantially preserves the most efficient relationship between the nozzle throat pressure and the combustion chamber pressure.

Another object of the invention is to provide a ram jet power plant of the character above referred to in which the several operative elements and controls are so constructed and related as to constitute a compact power plant unit of high efficiency having a minimum of external parts and projections which might produce aerodynamic drag in the event the unit is arranged for operation in a free air stream; for example, at the wing tip of an airplane.

A further object of the invention is to provide a ram jet engine capable of producing great thrust power in relation to its weight and that is capable of multi-sonic velocities.

A still further object of the invention is to provide a power plant of the class referred to that is simple and inexpensive to manufacture, having but few working parts so as to be adapted for embodiment in expendible units such as guided missiles.

Other objects and features of the invention will be readily understood from the following detailed description of a typical preferred form of the invention wherein reference will be made to the accompanying drawings in which:

Figure 1 is a side elevation of the ram jet power plant;

Figure 2 is an enlarged longitudinal sectional view of the power plant with certain parts appearing in side elevation, and with the intermediate portion broken away;

Figure 3 is an enlarged longitudinal sectional view of the forward portion of the power plant showing the ram inlet needle in its retracted position;

Figure 4 is a longitudinal detailed sectional view of the island portion of the unit illustrating certain controls and showing the fuel pump and air turbine;

Figure 5 is an enlarged longitudinal sectional view of the nozzle portion of the unit;

Figure 6 is an enlarged front view of the device;

Figure 7 is an enlarged detailed sectional view taken substantially as indicated by line 7—7 on Figure 6;

Figure 8 is a perspective view of a portion of the fuel vapor injecting system;

Figure 9 is a transverse detailed sectional view taken as indicated by line 9—9 on Figure 3;

Figure 10 is a fragmentary sectional view of the forward portion of the unit with the needle appearing in side elevation in its most forward position;

Figure 11 is a fragmentary sectional view illustrating one of the stabilizing strips of the fuel vaporizing tube assembly, the section being taken as indicated by the line 11—11 on Figure 2;

Figure 12 is a diagrammatic view illustrating the several controls embodied in the power plant: and,

Figures 13 to 17 inclusive are fragmentary diagrammatic views illustrating the manner in which the reflected shock waves converge in the inlet ram with the inlet needle in various positions.

The ram jet power plant of the invention may be said to comprise the combination of the following elements: a body or shell A having an inlet ram 11 and a nozzle 13, an inlet needle B, a stationary island C within the shell A, an automatic variable control means D for the needle B, a fuel vaporizing and injecting system E, an automatic and regulable control means F for the fuel system and an automatic control G for the propulsive nozzle 13.

The shell A which constitutes the body of the power plant is an elongate tubular element adapted to move in an air stream or to be submerged or partially submerged in the structure of an aircraft or guided missile. As illustrated, the major portion of the shell A is cylindrical or of uniform diameter, and the shell serves to house or contain the various other components of the engine, it being a feature of the invention that there is no necessity for protruding parts or assemblies which may offer drag or resistance to flight. In the preferred form of the invention the shell A comprises three main parts, the inlet ram 11, a combustion chamber section 12 and a nozzle section 13. These parts may be integral, although I may prefer to construct them as separately formed elements to facilitate fabrication and assembling.

The inlet ram 11 of the shell A is of the supersonic type and is in the nature of a tubular convergent-divergent diffuser type inlet controlled by the internal variable-position needle B to be subsequently described. The forward edge of the ram 11 is sharpened to offer a minimum of drag, and where the plant is designed for use in a free air stream, its external surface is smooth, regular and of gradually increasing diameter to reduce the drag to a minimum. The internal surface of the ram 11 also gradually increases in diameter and is smooth and free from irregularities. I prefer to construct the rear part of the inlet ram as a separate section 14, which may be considered either as a portion of the ram 11 or as a section connected intermediate the ram and the combustion chamber section 12. An internal reinforcing hoop 15 is secured in the rear end of the ram 11 by screws or bolts 16 and the section 14 telescopes over the hoop to be secured to the hoop and ram by welding 17. The section 14 is slightly rearwardly divergent or flared to continue the contour of the inlet ram 11. The tubular section 14 houses and supports certain controls and internal parts to be later described.

The combustion chamber section 12 may be a simple tubular part of uniform diameter throughout and is formed of corrosion resistant and heat resistant material such as "Inconel," or the like. As illustrated, the section 12 is of substantial length in relation to the other parts of the shell A to define an elongate passage or chamber of sufficient extent to assure full combustion of the vaporized fuel. The forward extremity of the section 12 is joined to the rear end of the section 14 by a continuous weld 18. An internal reinforcing hoop 19 is secured in the rear part of the section 12 by screws or bolts 20.

The nozzle or nozzle section 13 is a tubular part which telescopes over the hoop 19 and is joined or connected with the same by a continuous weld 21. In this connection, it will be observed that the several sections 11, 12, 13 and 14 of the shell A are integrally or rigidly joined to be free for expansion and contraction as a unit under temperature changes, there being no joints or seams where relative movement occurs by reason of thermal differentials. The nozzle section 13 is in the nature of a supersonic propulsive nozzle for ejecting the gases of combustion and the heated air at sonic and supersonic velocities. The forward portion of the section 13 may be of the same diameter as the section 12. An intermediate and somewhat rearward portion of the section 13 is shaped or contoured at 22 to curve rearwardly and inwardly toward the longitudinal axis of the assembly, and to then curve rearwardly and outwardly at 23 to a substantially cylindrical terminal wall 24. The curved portions 22 and 23 provide a restricted nozzle throat, the effective area of which is controlled by the nozzle member 108, to be later described. The internal surface of the nozzle section 13 is preferably covered or painted with ceramic paint or other heat resisting material, and the section may be formed of "Inconel," or other heat resistant alloy.

The annular external depression formed by the nozzle throat walls 22 and 23 is utilized to receive a mounting ring 25. The ring 25 may have the same external diameter as the combustion chamber section 12 and the forward portion of the section 13, and is secured to the section 13 by pins or rivets 26 passing through openings in spacing blocks 27. One or more lugs 28 are provided on the ring 25 to mount the engine, and a link 29 is connected between the lugs and a support (not shown) to permit free thermal expansion and contraction of the engine with respect to its supports. One or more mounting lugs 30 are secured to the above described reinforcing hoop 15, and project from the shell A to assist in mounting the engine.

The control for the rammed air inlet and diffuser 11 comprises the movable needle B in the inlet passage, the position of which is varied to control the compressive effect at the various translational velocities. The needle B is centrally and axially positioned in the ram inlet passage, and is movable with respect to a hollow stationary structure, which I have termed the island C. The needle and island together constitute an elongate streamlined assembly capable of elongation and contraction to govern the compressive ram action. The needle B comprises a sharp pointed forward tip **40**, and a tubular or hollow wall **41** extending rearwardly from the tip to have its rear portion telescope over the island. The wall **41** as illustrated, curves rearwardly and outwardly from the tip **40**, it being understood that the active surface of the needle may be comprised of a series of angular or conical surfaces of progressively increasing mean diameter. The curve or angle of the needle surface is of importance in causing the reflection of relatively gentle shock waves of air toward a limited area of the internal surface of the ram A. The lines **42** in Figures 3, 10 and 14 to 17 inclusive, indicate the reflected shock waves with the needle in the various positions it assumes at the different velocities of flight. It will be observed that forward and aft movement of the needle B moves the region of convergence of the shock waves forwardly and rearwardly along the interior of the ram A. The angulation or configuration of the needle is such that the reflected shock waves converge in a region of rather abrupt pressure rise adjacent the forward end of the ram. The concentration of the shock waves is utilized as a factor or medium of control, as will be later described in connection with the control means D. The rear portion of the needle shell or wall **41** is slightly curved or convex to carry out the streamlined configuration of the needle and island assembly. An internal partition or pressure bulkhead **44** is fixed in the needle some distance rearwardly of the tip **40** and is preferably partially spherical to present a concave rear face.

The island C is a hollow assembly stationarily supported in the inlet portion of the tubular shell A, and comprises a tubular forward section **45** and a rearwardly converging conoidal rear section **46**. The island is supported by spaced struts **47** of streamlined cross section, which are secured to the interior of the shell section **14** and welded or otherwise attached to the island section **46**. The struts are hollow or tubular to contain certain conduits to be later described, and the section **46** is ported to place the struts in communication with the interior of the island. A domed cap **49** is provided on the forward end of the island C and is freely received in the needle B. The trailing edge portion of the needle carries a sealing ring and bearing **48** which slides on the exterior of the cylindrical island section **45** to assist in guiding the needle for axial movement and to seal off the interior of the needle. The means for shiftably supporting and guiding the needle B further includes a tubular shaft **50** secured in a central opening in the cap **49** and passing forwardly through an opening **51** in the bulkhead **44**. A sliding seal is preferably provided in the opening **51** to prevent excessive leakage of air pressure through the opening. The needle tip **40** is socketed to freely receive the shaft **50** when the needle is in its rearmost position.

The automatic variable control means D for the movable inlet needle **50** governs the position of the needle in the inlet passage to obtain a most efficient compression ratio at the various speeds of operation and at different altitudes. The control system is characterized by its simplicity and fully automatic operation. It includes a sealed diaphragm chamber **52** contained within the cap **49**. A flexible diaphragm **53** passes through the chamber to divide its interior into two parts as shown in Figure 12. The diaphragm serves to control an air pressure bleed or vent passage **54** leading from the exterior of the shell A where it communicates with the atmosphere. It will be observed that the pressure bulkhead **44** and seal **48** close the opposite ends of a space within the needle B. The volume of this space is markedly reduced or lessened by the closed island section **45** and its cap **49** which together occupy the major portion of the interior of the needle. A pressure air port **55** in the wall of the needle section **41**, adjacent its rear end, maintains this space of limited volume in communication with the pressure air inlet passage of the ram. Thus the internal surface of the somewhat conoidal needle section **41** and bulkhead **44** are subjected to ram air pressure which tends to move the needle forwardly, this action being governed by controlling the vent passage **54**.

The above mentioned diaphragm **53** carries or operates a sliding piston and valve **56**, which controls the inlet **57** of the air vent passage **54**. The outer end of the piston-valve **56** is exposed to and acted upon by the pressure in the interior of the needle B, the pressure tending to move the piston-valve to an open position where the pressure-air may bleed out through the vent **54**.

The diaphragm **53** is in turn sensitive to or actuated by the position of convergence and intensity of the shock waves **42** reflected toward the inner wall and the ram **11** by the needle B. A tube **58** extends from the rear side of the diaphragm chamber **52** through one of the struts **47** and along the exterior of the shell A to the forward end portion of the ram inlet **11** where it communicates with the inlet passage at **9**. A similar tube **59** extends from the forward side of the diaphragm chamber **52** to the forward portion of the ram inlet where it communicates with the inlet passage at a point **8** some distance rearwardly from the point **9** of communication of the tube **58** with the passage. In practice, the point **8** may be in any suitable location at the rear of the point **9**. The space or area adjacent the open forward end **9** of the tube **58** is the zone traversed by the converging shock waves **42** during movement of the needle B between its extended and retracted positions accompanying variations in the velocity of flight.

The control D just described serves to move the needle B forwardly as the forward speed of the engine increases and moves the needle rearwardly as engine speed decreases, thus affording efficient compression of the air by the ram action at different speeds in the supersonic range. Figures 13 to 17 depict in a diagrammatic and generalized manner, the position of the needle B, and the position and character of the shock waves **42** during various translational velocities of the power plant. At the initiation of engine operation, the needle B is in its rearmost position, and as the speed of the engine increases, the needle is moved forwardly by the air pressure building up in the interior. This forward movement of the needle continues until the needle reaches a position where the reflected converging shock waves **42** move rearwardly beyond the tap **9** to substantially decrease the pressure in the tube **58** and the rear side of the diaphragm chamber **52**. Thereafter, the position of the needle B is determined by the equilibrium of pressures on the internal and external surfaces of the needle, this equilibrium being dependent upon engine speed; i. e., translatory velocity. The action of the needle B and its control is described in more detail below.

Now referring to Figure 13, it will be assumed that the engine is traveling at the speed of sound or a speed approaching the speed of sound; for example, at a Mach number of 1.0. At this speed the needle B is in its rearmost position, the pressure admitted by the bleed **55** to the interior of the needle being insufficient to move the needle forwardly. No shock waves are formed at this velocity but a bow wave **140** is formed in front of the needle B and the engine. In Figure 14 it may be assumed that the power plant has exceeded the speed of sound, traveling at a Mach number of 1.4, and the initial shock wave **42** is reflected from the needle B at an angle of approximately 45° to the longitudinal axis of the needle. This initial shock wave may or may not impinge against the lip portion of the ram inlet **11**. Although the pressure within the needle B and in the forward side of the diaphragm chamber **52** is building up at this time, it has not reached a value sufficient to move the needle forwardly. When the engine attains a higher velocity, say a speed equivalent to a Mach number of 2.0, by its own propulsive force, or with the assistance of rocket power or the like, the pressure admitted to the interior of the needle B by the port **55** moves the needle forwardly against the action of the ram pressure. Thus in Figure 15 the needle has moved forwardly to a position where the reflected shock waves **42** impinge against the internal lip portion of the ram **11** in the vicinity of the tap **9**. It will be observed that the automatic forward adjustment of the needle B effects utilization of the several shock waves **42** produced at this speed by bringing them within the entrance of the ram **11** and an efficient compression of the air is obtained. The area of convergence of the shock waves **42** adjacent the tap **9** constitutes a region of increased pressure; however, the pressure at the tap **8** is always greater than the pressure at the tap **9**. The line **59** carries this greater pressure to the front side of the diaphragm **53**. This pressure admitted by the line **59** opposes the pressure within the needle B acting on the piston **56** and opposes the pressure admitted to the diaphragm chamber **52** by the tap **9** and line **58**. When the pressure acting on the front side of the diaphragm overcomes the pressures on its rear side, the piston **56** moves rearwardly to limit bleeding of pressure air from the vent **54**. When the angles of the shock waves are decreased further, due to additionally increased engine speed, their point of convergence moves rearwardly away from the pressure tap **9**, thus reducing the pressure at the rear side of the diaphragm **53**. As a result, the diaphragm **53** moves to the rear and the piston-valve **56** closes or further restricts the bleed **54** so that pressure builds up within the needle B to move the needle forwardly. This forward movement of the needle returns the point of convergence of the shock waves to the vicinity of the tap **9** to terminate forward movement of the needle. In practice the diaphragm **53** will assume a condition of equilibrium to stabilize the needle B in proper adjusted position for any given velocity of the engine. In Figure 16 is may be assumed that the unit has attained a speed equivalent to a Mach number of 2.50 and the resultant increase in the pressure on ram-compressed air admitted into the needle B by the port **55** has moved the needle forwardly. This forward adjustment of the needle causes the shock waves **42** of proportionately increased Mach number to be reflected in a manner to converge adjacent the tap **9** or in the region between the taps **8** and **9**, thus preserving the efficient compression obtained by the utilization of the gentle shock waves. It will be observed that as the speed of the power plant increases, the angles of the shock waves **42** with relation to the longitudinal axis of the needle B are decreased, and the forward automatic adjustment of the needle compensates for this change in angularity to keep the area of convergence of the shock waves within the adjacent forward lip of the ram **11**. As with the earlier speeds, the ram-compressed air admitted into the needle B is increased to move the needle forwardly and the pressure in the forward side of the diaphragm chamber is also increased. However, this increase in the pressure acting on the forward side of the diaphragm is opposed by the same pressure acting on the piston **56** and by the increased air pressure admitted to the rear side of the diaphragm by the tap **9** and line **58**. As a result, the piston **56** serves to control the bleed of air pressure from the needle so as to maintain the needle in its adjusted location. Figure 17 illustrates the position of the needle B when the power plant has attained a Mach number of 3.0 and shows the needle in an advanced position where it directs or reflects the shock waves **42** so as to converge in a region adjacent the tap **9** or between the taps **8** and **9** so as to preserve the efficient compressive action at the higher velocity. The diaphragm control acts to retain the needle B in this position so long as the velocity is preserved. When the speed of the engine is reduced, the needle B automatically moves to the rear as will be readily understood, the diaphragm control serving to cause such movement of the needle in proportion to the reduction in velocity. This maintains the area of convergence of the shock waves **42** within the lip portion of the ram **11**; i. e., between the pressure taps **8** and **9**.

The fuel system E effects thermal vaporization of the fuel and injects the vaporized fuel into the airstream at the forward end of the combustion chamber. The system includes fuel pump means for delivering liquid fuel under pressure to a vaporizing means. The pump is preferably contained in the island C and is driven by an air turbine at the rear portion of the island. I have shown a fuel supply pipe **60** passing inwardly through one of the struts **47**, from a fuel source (not shown), and provided with an elbow **61** having a rearwardly extending arm which is substantially co-axial with the island assembly. A centrifugal fuel pump **62** has its inlet or low pressure side connected with the elbow **61** and its high pressure side delivers fuel to pipes **63** extending outwardly and rearwardly through the struts **47**. The shaft **64** of the pump is tubular, and is supported by spaced bearings **65** carried in a housing **66**. The housing **66** has an outwardly extended peripheral flange **67** continuing rearwardly from the wall of the island and provided with spaced lugs **68** bolted to a surrounding shroud **69**. The shroud in turn is carried by the spaced struts **47**. The flange **67** and the shroud **69** define an annular rearwardly converging air passage **70** which is co-axial with the main air passage of the power plant. A substantially conical cap **71** is secured in the shroud in spaced relation to its internal surface to provide or leave a rearward continuation of the passage **70**. This continuation of the passage is of rearwardly increasing capacity. Spaced rivets or bolts **72** may mount the cap **71** in the shroud 69. The cap 71 is spaced rearwardly from the housing flange 67 to leave an annular gap for an air turbine wheel 73. The wheel 73 is fixed to the pump shaft 64 and its blades operate in the air passage 70. The structure just described is best illustrated in Figures 3 and 4. It will be seen that air under pressure flowing through the passage 70 at a substantial velocity drives the turbine wheel 73, which in turn drives the fuel pump 62. The entrance of the annular passage 70 surrounds the aft or trailing portion of the island, and serves as a means for sucking away or removing the boundary layer air from island and needle B. This substantially increases the efficiency of the supersonic inlet ram or convergent-divergent inlet diffuser.

The vaporizing means of the fuel system E is associated with the combustion chamber to utilize the heat of combustion to vaporize the fuel before it is delivered to the injecting means. The lines 63 from the pump 62 lead through the struts 47 to an annular and tubular header 74 engaged within the shell section 14 and associated with the struts 47; see Figure 3. A similar header 75 is arranged rearwardly of the header 74, the two members preferably being substantially square in transverse cross section and secured in abutting relation. A third manifold ring or header 76 of similar configuration is secured in the rear portion of the combustion chamber section 12 adjacent the above described hoop 19 as shown in Figure 5. A series of circumferentially spaced vaporizing tubes 77 have their forward ends in communication with the fuel supply header 74 and pass rearwardly through openings in the walls of the header 75. The tubes 77 continue rearwardly in spaced adjacent relation to the wall of the combustion chamber section 12, and have their rear ends received in openings in the wall of the rear header 76. A similar set of tubes 78 have their forward ends in communication with the fuel receiving header 75 and their rear ends are in communication with the rear header 76. I prefer to alternate the tubes 77 and 78 in a single tubular or annular series as illustrated. It will be apparent that fuel supplied to the header 74 by the pump 62 flows rearwardly through the tubes 77 and then forwardly through the tubes 78 to the header 75, and during this circuit the fuel is effectively vaporized. The tubes 77 and 78, and the manifolds 74, 75 and 76 are preferably formed of corrosion and heat resistant material such as "Inconel," and strips 80 of the same or similar material are laced around or through the annular series of tubes 77 and 78 at spaced points to stabilize the tubes. Figure 11 illustrates the manner in which the strips 80 are trained between the adjacent tubes.

The fuel vaporized in the tubes 77 and 78 is delivered to vapor injection devices arranged in the forward portion or entrance of the combustion chamber. These devices are best illustrated in Figures 3, 7, 8 and 9. A plurality of circumferentially spaced tubular struts or bars 81 extend radially inward from the vapor header 75 and are spaced between the supporting struts 47. Partitions 82 in the rear portions of the struts 47 define vapor passages 83 therein. The inner wall of the tubular vapor header 75 has spaced ports 84 which communicate with the interiors of the bars 81 and passages 83 to deliver vapor thereto for inward flow to the injectors.

The injectors comprise what I will term cup strips 84 arranged on the bars 81 and struts 47. The cup strips 84 are preferably arranged in concentric radially spaced annular rows as shown in Figure 9, and although the strips may be provided in two or more spaced transverse planes, I have shown all of the strips in a single transverse or diametric plane. The cup strips 84 are curved or arcuate and are substantially U-shaped in transverse cross section, having curved forward end walls and spaced substantially parallel or concentric side walls which extend rearwardly relative to the direction of air flow. As shown in the drawings, the cup strips 84 are secured intermediate their ends to the struts 47 and bars 81 so that their side walls extend freely beyond the struts and bars, both in the rearward and circumferential directions.

Each circular row of cup strips 84 embodies a multiplicity of the strips related to have their ends in spaced adjacent relation whereby their interiors are, in effect, in communication but the individual strips are free for independent thermal expansion and contraction. The several circular rows of cup strips 84 are spaced and related as shown in Figure 9 so that the outer row is adjacent the wall of the shell A, and the inner row is in spaced surrounding relation to the above described shroud 69. The vaporizing strips are secured to the struts 47 and bars 81 by welding, or the like, so as to be rigid and stationary. Ports 85 are provided in the walls of the bars 81 and struts 47 to deliver fuel vapor to the interiors of the cup strips 84, and the inner ends of the bars and passages 85 are open to the innermost strips. This vapor travels or flows circumferentially in the cup strips and moves axially or downstream. In order to prevent stagnation of the vapor in the strips 84, and to assure a more complete and uniform combustion of the vapor by means of controlled primary combustion, I provide a series of spaced ports or openings 86 in the forward walls of the strips. The capacity and spacing of these openings 86 are such that the flames are not extinguished by the air admitted by them into the interiors of the cup strips. It will be seen that the vapor injecting means provides and maintains an extensive and uniform dispersion of fuel across substantially the entire air stream at the entrance of the combustion chamber. The struts 47, bars 81 and cup strips 84 are preferably constructed of "Inconel," or the like.

Means are provided for igniting the fuel vapor at the injection system just described. As best shown in Figure 7, a glow plug 92 is threaded through a boss 87 on the shell A and passes inwardly through openings in the shell and header 75 to project into one of the hollow bars 81. The resistance wire of the glow plug for igniting the fuel is housed in a perforate shield 88. A liquid fuel line 89 enters the shell A and has a jet 90 directed to impinge a stream of fuel against the shield and glow plug. A short tap or pipe 91 leads from the interior of the liquid fuel header 74, and is arranged to direct a small stream of fuel against the shield and glow plug. A flame initiated at the glow plug travels out through the bar 81, and the openings 85, and progresses through the several cup strips 84 to ignite the fuel in the strips. In practice, fuel from the pipe 91 will usually be employed to start the engine. However, in the case of certain fuels of low inflammability, and under difficult starting conditions, additional fuel or special fuel may be supplied through the pipe 90 to assist in starting. The fuel vaporizing and injecting system and the igniting means just described form the subject matter of my copending application Serial Number 783,536, filed November 1, 1947.

With the fuel vaporizing and injecting means E described above, the air-fuel ratio remains substantially constant, irrespective of the translational speed and altitude, the centrifugal fuel injecting pump 62 being driven by the rammed air supply through the medium of the turbine 73 to preserve this ratio. The fuel pump 62 and turbine 73 are related and designed to provide an air-fuel ratio of approximately 18 to one. When the translational movement of the engine reaches the value of a Mach number of approximately 3, this air-fuel ratio causes the spouting velocity of the air and gases of combustion from the nozzle 13 to be approximately twice that of the translational velocity, bringing the point of maximum thrust into coincidence with that required for maximum range of flight and best economy. At lower flight Mach numbers the air-fuel mixture should be leaner, although it may be important and desirable to obtain maximum thrust under certain conditions at such lower velocities. It may also be necessary to vary the thrust at any velocity of flight. The control means F is provided to permit regulation or variation of the thrust as may be required regardless of fuel economy. The control means F is in the form of a controlled by-pass system between the low pressure pipe 60 of the pump 62 and one of its high pressure pipes 63. The by-pass 93 has a nozzle-like part 150 in the fuel supply pipe 60 arranged to discharge the by-passed fuel downstream or in the direction of fuel flow. This positioning of the part 150 prevents cavitation at the pump 62. An adjustable constant flow valve is interposed in the by-pass 93. This valve includes a stationary island 94 of streamlined configuration arranged in the path of fuel flow and a "floating" tubular venturi 95 movable toward and away from the island so as to cooperate therewith in restricting the fuel flow through the by-pass 93 to a greater or lesser degree. The Venturi member 95 carries a piston 96 operating in a cylinder 97 connected in the by-pass line 93. The passage 98 of the Venturi member 95 continues through the piston 96, having its entrance mouth at the upstream side of the piston and its exit in opposed relation to the island 94. Relatively small ports 99 lead from the restricted throat of the Venturi passage 98 to the downstream side of the cylinder 97 to balance the pressures on the opposite sides of the piston. It will be seen that with the valve structure just described the Venturi member 95 is constantly urged toward the island 94, by the fuel flow, to restrict the flow.

The fuel control means F serves to govern or regulate this tendency of the Venturi member 95 to move toward the closed position, and thus regulates fuel flow the by-pass 93. A rod 100 is connected with the upstream end of the piston 96 and extends from the cylinder 97 to have its outer end connected with a tension spring 101. The spring 101 is in turn connected with a rocker or lever 102 at a point intermediate its ends. The lever or rocker 102 has one end fulcrumed at 103 to a member 104, which is capable of adjustment or setting in any selected position. Although any appropriate means may be provided to adjust the member 104, I have shown a Bowden wire 105 connected with the member and extending from the engine for association with a manual control, or any other instrumentality for effecting a change in the air-fuel ratio in the combustion chamber. The opposite end of the rocker 102 is operatively connected with the inlet needle B so that the air-fuel ratio is automatically maintained to obtain optimum economy at various velocities. The connection between the rocker and the needle may comprise a rod 106 pivotally secured with the long arm of the rocker and extending forwardly for connection with a clip 107 on the bulkhead 44 of the needle.

It will be seen that with a given setting of the fulcrum control member 104, forward motion of the needle B accompanying increased velocity of flight moves the rocker 102 to reduce the tension in the spring 101, allowing the Venturi 95 to move toward the island 94, thereby reducing the fuel flow through the by-pass 93 and increasing the delivery of fuel to the combustion chamber up to the value required for efficient engine operation. When the needle B moves rearwardly at a reduced Mach number of engine operation, the rocker 102 is moved to increase the tension in the spring 101 and thus move the venturi away from the island 94 to allow increased flow through the by-pass 93, reducing the delivery of fuel to the combustion chamber. The regulable fulcrum member 104 and its associated manual, mechanical or remote control forms an overriding regulation for the fuel by-pass system. When the member 104 is moved forwardly, the tension in the spring 101 is reduced to lessen fluid flow through the by-pass 93 and accordingly increase the delivery of fuel to the combustion chamber and obtain a greater thrust. Conversely, when the member 104 is moved to the rear, tension in the spring 101 is increased, moving the venturi 95 away from the island to allow an increased fuel flow through the by-pass and therefore reduce the delivery of fuel to the combustion chamber. It will be observed that the out-put or thrust of the engine can be regulated independently of the automatic control by merely changing the position of the fulcrum member 104.

The control G for the propulsive nozzle 13 includes a throat member 108 movable in the nozzle and a mechanism or control for automatically shifting or adjusting the throat member. The throat member 108 is preferably a tubular or hollow element formed of heat resistant material such as a ceramic material. The major portion of the member 108 is preferably substantially spherical to obtain a most efficient action in the supersonic nozzle 13, while the rear portion of the member is extended and defined by a reverse curve. The nozzle or throat member 108 is slidably or shiftably supported on a central tube 109 secured in the rear end of the above described shroud 69 and extending rearwardly through the combustion chamber to the extremity of the nozzle 13. The tube 109 serves to conduct the air under pressure which has been exhausted by the turbine 73 and shroud 69, and carries this air rearwardly for ultimate discharge at the nozzle region of the engine to assist the thrust or propulsive action. The rear portion of the tube 109 may be pinched in or reduced in diameter to obtain a nozzle effect for the discharging air and to preserve a desirable back pressure in the tube for the cooling of the throat member 108 and the other parts, as described below. The tube 109 is formed of heat resistant material and is preferably painted with ceramic paint.

The throat member **108** has a pin and slot connection with the tube **109**. Axial slots **110** are formed in diametrically opposite wall portions of the tube and a rod **111** carried by the throat member extends through the slots. A tubular spacer **112** is provided on the rod within the tube **109**. It will be observed that the slots **110** maintain the interior of the throat member **108** in communication with the tube so that cooling air is free to flow from the tube into the member. A series of spaced ports **113** pass through the rear wall portion of the throat member to exhaust the cooling air and thus maintain a circulation of air through the member. Furthermore, the sliding fit of the throat member **108** on the tube **109** may be such as to allow the limited escape of cooling air under pressure to further assist in maintaining an air flow through the member. From the above it will be seen that the exhaust of the air turbine **73** is utilized to cool the tube **109**, the throat member **108** and the parts associated therewith.

It is desirable to provide a means of support for the tube **109** in the rear portion of the engine. I have shown two spaced struts **114** secured to the tube as by welding, and suitably attached to the wall of the nozzle section **13** to carry the rear portion of the tube. The struts **114** are preferably streamlined in transverse cross section, and are tubular. As shown in Figures 5, the struts **114** have their interiors in communication with the tube **109** to receive cooling air therefrom, and the outer ends of the tubes are open to discharge into the atmosphere. During operation of the power plant there is a continuous flow of cooling air through the supporting struts **114**. The tube **109** and struts **114** are preferably formed of a heat resistant material such as "Inconel," and may be painted with a ceramic paint. The above described fuel pump and drive therefor and the cooling of the nozzle parts by the exhaust from the air turbine are covered by my copending application Serial Number 780,864, filed October 20, 1947.

The nozzle control G further includes a rod **115** connected with the spacer **112** and cross rod **111** of the throat member **108**. This rod **115** extends forwardly through the tube **109** and is supported therein, by spaced bearings **117**. As best shown in Figure 4, the rod **115** continues forwardly through the axial opening **116** of the pump shaft **64**, and the rotor of the pump carries a sealing means **117** for preventing the leakage of fluid around the rod. The rod **115** passes forwardly through the elbow **61** and a packing gland **118** on the elbow to continue forwardly into a cylinder **119**. A sleeve **120** on the rod **115** slidably enters the opening **121** of the above described shaft **50**, the shaft **50** having its end secured in an opening in the forward wall of the cylinder **119**. A piston **122** is fixed on the sleeve **120** to operate in the cylinder **119**, it being noted that the cylinder is of substantial diameter. The cylinder **119** is suitably secured in the above described island C by a series of bolts **123**.

The propulsive nozzle control G further includes a pressure and bleed system for actuating and controlling the piston **122**, this mechanism being best illustrated in Figures 4 and 12. The forward end of the cylinder **119** is vented to the atmosphere by a vent pipe **124**, which may pass rearwardly through the island C and then out through one of the struts **47**. The system just mentioned includes a pressure line **125** leading from the entrance portion of the combustion chamber to the rear end of the cylinder **119** to deliver air under pressure to the cylinder. The line **125** may pass rearwardly through the island C, and then through one of the struts **47** to communicate with the main air passage of the engine at the upstream side of the fuel injecting strips **84**. A pressure bleed line **126** extends from the rear end of the cylinder **119** to the atmosphere and may pass outwardly through the island C and one of the struts **47**. The control system includes a relay valve **127** interposed in the bleed line **126**, the valve being actuated by instrumentalities sensitive to pressures at the entrance of the combustion chamber and at the throat of the propulsive nozzle **13**.

The valve **127** has a closure **128** secured to a rod or stem **129** and cooperating with a seat **130** to control flow through the bleed **126**. An evacuated bellows **131** is secured to one end of the valve stem **129** and is contained in a closed chamber **132**. A line **133** maintains the chamber **132** in communication with the throat of the supersonic propulsive nozzle **13**. The line **133** may extend out through a strut **47** and continue along the exterior of the shell A to have its end open at the most restricted portion of the nozzle **13**. The resiliency of the bellows **131** tends to move the closure **128** toward the seat **130**, while the pressure conveyed from the nozzle throat by the line **133**, acting upon the bellows, tends to move the closure away from the seat. A second evacuated bellows **134** is secured to the other end of the valve stem **129** and is subject to the pressure existing at the entrance to the combustion chamber. The bellows **134** is housed in a chamber **135**, and a pipe or line **136** maintains the chamber in communication with the entrance portion of the combustion chamber. The line **136** extends through the island C and one of the struts **47** to have its end open to the main air passage adjacent the upstream side of the vapor injecting system. In practice, the line **136** may communicate with the main air passage adjacent the open end of the line **125**.

The control for the throat member **108** as just described, operates on the principle that the critical pressure in the throat of the nozzle **13** should be approximately .53 times the pressure at the entrance of the combustion chamber, assuming that the flow at the nozzle throat has a velocity of one Mach number. To obtain the proper action of the relay valve **127**, the bellows **131** and **134** are proportioned one to the other to preserve this ratio or relationship. For example, assuming the effective area of the evacuated bellows **131**, which is subjected to nozzle throat pressure, to be unity, the effective area of the bellows **134**, which is subjected to initial combustion chamber pressure, should be approximately .53. Gas pressures in the propulsive nozzle region result in a force tending to move the nozzle member **108** downstream. On the other hand, the pressures acting on the rear side of the piston **122**, tend to move the throat member **108** upstream. This latter action is subject to or limited by the value of approximately .53 as impressed on the relay valve **127** and therefore upon the piston **122** by the proportioned bellows **131** and **134**.

Assuming that the throat member **108** is in a rearmost position where the throat of the nozzle **13** is restricted, the pressure at the forward end of the combustion chamber will build up, and this pressure applied to the bellows 134 contracts the bellows to move the closure 128 toward the seat 130. This restricts the bleed 126 and pressure builds up in the rear end of the cylinder 123 to move the piston 122 and throat member 108 forwardly. This "opens" the nozzle, reducing the combustion chamber pressure. On the other hand, when the pressure at the entrance of the combustion chamber falls below the optimum by reason of the position of the throat member 108, or for other causes, the pressure on the bellows 134 is lessened, and while the pressure on the bellows 131 may remain relatively high, the valve closure 128 is moved away from its seat 130. This allows an increased bleed of pressure from the cylinder 123 and the pressures acting on the throat member 108 move the member rearwardly to restrict the nozzle throat and compensate for the reduced initial combustion chamber pressure. The control G will usually remain in a condition of equilibrium to preserve the proper relationship between the combustion chamber pressure, and the spouting velocities and pressures at the nozzle to obtain maximum propulsive efficiency at the various velocities of flight.

Although the operation of the several components of the power plant has been described in detail above, it is believed desirable to summarize the operation of the plant as a whole. It may be assumed that the engine is to be associated with an airborne missile or aircraft to form a propulsive means therefor and that the missile or craft carries the fuel supply and the controls for the starting system and fulcrum member 104. The missile or aircraft is brought up to or beyond the speed of sound, or a Mach number of one, by other propulsive means; for example, by rocket power or turbo-jet propulsive devices. It is at this speed, or above the speed, that the ram jet unit becomes efficient as a propulsive means. To start the engine, current is supplied to the glow plug 92, and fuel is supplied to either the main fuel line 60 or the starting jet 90, or both. Air flow through the annular passage 70 operates the air turbine 73, which in turn drives the pump 62 to supply fuel to the vaporizing means. The fuel flows through the tubes 77 and 78 to the struts 47 and bars 81, and a small stream of the fuel is discharged against the glow plug 92 by the jet 91. The fuel is ignited at the glow plug 92 and as described, the flame progresses through the adjacent bar 81 to the several annular series of cup strips 84 to provide flames at the several cup strips. The fuel employed may be gasoline, coal oil, or other appropriate liquid fuel.

The supersonic ram inlet 11 and its shock wave reflecting needle B effects a compression of a large volume of air supplied to the combustion chamber. For example, at a speed equivalent to a Mach number of 1.7, the compression ratio will be approximately 3.6, and at a Mach number of 3.0 the compression ratio will exceed 17.0 to one.

During operation of the power plant the fuel is thoroughly vaporized during its passage through the tubes 77 and 78, and is efficiently consumed upon admission to the high pressure combustion chamber at the cup strips 84. It will be observed that the vaporizing means 77—78 increases the efficiency of the plant by a regenerative action, and also protects, at least to some extent, the walls of the tubular shell A. The gases of combustion and the heated air are spouted from the nozzle 13 at a high velocity to produce a substantial forward thrust. As above described in connection with the detailed description of the fuel control F, the centrifugal pump 62 driven by the air turbine 73 and the associated by-pass control, maintain an efficient air-fuel ratio in the combustion chamber at the various speeds of operation. The movement of the needle B in the ram inlet 11 controls flow through the fuel by-pass 93 to automatically preserve the optimum air-fuel ratio. The means D which automatically adjusts the position of the needle B brings the needle into the position where it most effectively utilizes the highly efficient compressive action of the gentle shock waves 42 in the ram inlet 11. This automatic adjustment of the needle B and the action of the shock waves 42 have already been described in detail. The fuel supply system in addition to being automatically controlled by movement of the needle B, is capable of adjustment or regulation by movement of the fulcrum member 104. As above noted, this member 104 may be shifted or set either manually, by an automatic mechanism, or by a remote control to obtain an increased or decreased thrust at will. Thus, although the power plant will operate automatically to obtain optimum efficiency at any speed, it may be controlled at will to regulate or vary its speed.

The control G automatically regulates the effective area of the propulsive nozzle 13 to produce an effective propulsion action at the various compression ratios and air-fuel ratios. It has already been described how the control G operates to maintain a substantially constant ratio of approximately one to .53 between the initial combustion chamber pressure and the critical nozzle throat pressure.

The power plant embodies a minimum number of working parts housed and arranged in such a manner that they do not constitute aerodynamic drag-producing projections. The working parts are within the shell A and the majority of such parts are within the needle and an island assembly B—C where they do not in any way obstruct the principal air passage. The ram jet unit of this invention is simple and inexpensive to manufacture, and therefore well adapted for use as an expendible power unit or propulsion device for guided missiles, etc.

Having described only a typical form of the invention, I do not wish to be limited to the specific details herein set forth, but wish to reserve to myself any variations or modifications that may appear to those skilled in the art and/or fall within the scope of the following claims.

I claim:

1. A reactive propulsion engine comprising a tubular shell having an inlet ram at its forward end and a propulsive nozzle at its rear end, heat generating means in the shell in downstream relation to the inlet, an island in the inlet portion of the shell, a needle movable in the ram inlet and operable to reflect shock waves against the wall of the inlet to effect an efficient compression of the air, the needle having a pointed forward end and having an external surface developed to reflect said shock waves in convergence toward the wall of the ram inlet throughout the entire range of movement of the needle in the inlet, and means in the island for controlling the position of the needle.

2. A reactive propulsion engine comprising a tubular shell having an inlet ram at its forward end, and a propulsive nozzle at its rear end, heat

generating means in the shell in downstream relation to the inlet, a movable member for governing flow through the tubular shell, a pressure tap in the wall of the shell, and a servo mechanism responsive to the pressure in said tap for moving said member.

3. A reactive propulsion engine comprising a tubular shell having an inlet ram at its forward end, and a propulsive nozzle at its rear end, heat generating means in the shell in downstream relation to the inlet, an island in the inlet portion of the shell, a movable member for governing flow through the tubular shell, pressure taps communicating with the interior of the shell at given regions thereof, and a servo mechanism in the island sensitive to the pressures at said taps for governing the position of said member.

4. In a reactive propulsion engine, a tubular shell, an inlet ram at the forward end of the shell comprising an annular supersonic diffuser, a substantially central needle movable axially in the inlet and operable to reflect supersonic shock waves against the wall of the inlet, the needle being shaped to cause a convergence of the shock waves toward the wall of the inlet, and means sensitive to the location of substantial convergence of said shock waves for moving the needle axially of the inlet.

5. In a reactive propulsion engine, a tubular shell, an inlet ram at the forward end of the shell comprising an annular supersonic diffuser, a substantially central needle movable axially in the inlet and operable to reflect supersonic shock waves against the wall of the inlet, the needle being shaped to cause a convergence of the shock waves toward the wall of the inlet, a pressure tap in the wall of the inlet in the general zone of convergence of said shock waves, and servomotor means sensitive to pressure in said tap to move the needle axially so as to retain the region of convergence of the shock waves in the vicinity of said tap irrespective of an increase or decrease in the supersonic velocity of the engine.

6. In a reactive propulsion engine, a tubular shell, an inlet ram at the forward end of the shell comprising an annular supersonic diffuser, a substantially central needle movable axially in the inlet and operable to reflect convergent supersonic shock waves toward the wall of the inlet, and means for moving the needle axially in the inlet to maintain the region of convergence of the waves in the entrance portion of the inlet during operation of the engine at various Mach numbers, said means including a pressure tap in said entrance portion of the inlet, and a motor mechanism sensitive to the pressure at said tap to cause forward movement of the needle when the pressure at the tap drops by reason of said shock waves moving to the rear of the tap upon an increase in the speed of the engine.

7. In a reactive propulsion engine, a tubular shell, an inlet ram at the forward end of the shell comprising an annular supersonic diffuser, a substantially central needle movable axially in the inlet and operable to reflect convergent supersonic shock waves toward the wall of the inlet, a pair of axially spaced pressure taps in the wall of the inlet adjacent the entrance thereof, the needle being hollow at its downstream side, a stationary island in the shell closing the downstream end of the movable needle, means for admitting pressure air into the needle to urge it forwardly, and valve means sensitive to the pressures in said taps for controlling the bleeding of pressure air from the needle to maintain the region of convergence of said shock waves between said taps at various supersonic speeds of the engine.

8. In a reactive propulsion engine, a tubular shell, an inlet ram at the forward end of the shell comprising an annular supersonic diffuser, a substantially central needle movable axially in the inlet and operable to reflect convergent supersonic shock waves toward the wall of the inlet, a pair of axially spaced pressure taps in the wall of the inlet adjacent the entrance thereof, the needle being hollow at its downstream side, a stationary island in the shell closing the downstream end of the movable needle, means for admitting pressure air from the diffuser into the needle to urge the needle forwardly, a valve for venting pressure air from the needle, and diaphragm means for controlling the valve and sensitive to the pressures at said taps to regulate the valve in a manner to maintain the region of convergence of said shock waves substantially between said taps at various supersonic velocities of the engine.

9. A reactive propulsion power plant comprising a tubular shell having a ram inlet at one end and a propulsive nozzle at the other end, heat generating means in the shell between its ends, a member movable in the inlet to control the same, means responsive to aerodynamic conditions in the ram inlet for moving the member and for controlling the heat generating means.

10. A reactive propulsion engine comprising a tubular shell having an inlet at its forward end and a propulsive nozzle at its rear end, heat generating means in the shell between said inlet and nozzle, a member movable in the inlet to control the same, means responsive to aerodynamic conditions in the inlet for moving the member, and a control for the heat generating means regulated by movement of the member.

11. A reactive propulsion engine comprising a tubular shell having an inlet at its forward end and a propulsive nozzle at its rear end, heat generating means in the shell between said inlet and nozzle, a member movable in response to variations in the supersonic velocity of the engine, and a control for said heat generating means regulated by movement of the member.

12. In a power plant of the reactive propulsive type, a ram inlet, a movable needle in the inlet having a forwardly convergent surface region for reflecting shock waves to the wall of the inlet when the power plant is operating at supersonic velocities, and means for moving the needle forwardly as the velocity increases so that said surface region reflects the shock waves toward the lip portion of the inlet at such increased velocities, said means including a servo mechanism for moving the needle, and a control for said mechanism sensitive to the pressure in the lip portion of the inlet.

13. A reactive propulsive unit comprising a tubular shell having an inlet ram at its forward end comprising an annular convergent-divergent diffuser, the shell having an intermediate combustion chamber and a propulsive nozzle at its rear end, a substantially central island in the diffuser, a needle shiftably telescoping over the island and presenting a forwardly convergent surface for reflecting shock waves toward the wall of the inlet when the unit is traveling at supersonic speeds, control means in the island for moving the needle forwardly upon an increase in velocity of the unit to cause said shock waves to be reflected into the forward portion of the inlet at

such increased speeds, means for injecting fuel into the combustion chamber, a control for the fuel injecting means governed by the position of the needle, and means for controlling the effective area of said nozzle.

14. A reactive propulsive unit comprising a tubular shell having an inlet ram at its forward end comprising an annular convergent-divergent diffuser, the shell having an intermediate combustion chamber and a propulsive nozzle at its rear end, a substantially central island in the diffuser, a needle shiftably telescoping over the island and presenting a forwardly convergent surface for reflecting shock waves toward the wall of the inlet when the unit is traveling at supersonic speeds, control means in the island for moving the needle forwardly upon an increase in velocity of the unit to cause said shock waves to be reflected into the forward portion of the inlet at such increased speeds, a fuel supply system for introducing fuel into the combustion chamber, a control for said system regulated by movement of the needle, and an overriding control for said system operable independently of the position of the needle.

15. A reactive propulsive unit comprising a tubular shell having an inlet ram at its forward end comprising an annular convergent-divergent diffuser, the shell having an intermediate combustion chamber and a propulsive nozzle at its rear end, a substantially central island in the diffuser, a needle shiftably telescoping over the island and presenting a forwardly convergent surface for reflecting shock waves toward the wall of the inlet when the unit is traveling at supersonic speeds, control means in the island for moving the needle forwardly upon an increase in velocity of the unit to cause said shock waves to be reflected into the forward portion of the inlet at such increased speeds, pump means for supplying fuel to the combustion chamber, a by-pass between the high and low pressure sides of the pump, a valve for controlling the by-pass to regulate the delivery of fuel to the combustion chamber, and an operative connection between the needle and valve whereby the position of the valve is determined by the position of the needle.

16. A reactive propulsive unit comprising a tubular shell having an inlet ram at its forward end comprising an annular convergent-divergent diffuser, the shell having an intermediate combustion chamber and a propulsive nozzle at its rear end, a substantially central island in the diffuser, a needle shiftably telescoping over the island and presenting a forwardly convergent surface for reflecting shock waves toward the wall of the inlet when the unit is traveling at supersonic speeds, control means in the island for moving the needle forwardly upon an increase in velocity of the unit to cause said shock waves to be reflected into the forward portion of the inlet at such increased speeds, pump means for supplying fuel to the combustion chamber, a by-pass between the high and low pressure sides of the pump, a valve for controlling the by-pass to regulate the delivery of fuel to the combustion chamber, an operative connection between the needle and valve whereby the position of the valve is determined by the position of the needle, and a member adapted for manual or remote operation for regulating the valve independently of the position of the needle.

17. A reactive propulsion power plant comprising a tubular shell having a supersonic inlet ram at its forward end, a combustion chamber, and a propulsive nozzle at its rear end, a needle in the inlet shaped to reflect supersonic shock waves to the wall of the inlet, means for supplying fuel to the combustion chamber, and means sensitive to the Mach number of the reflected shock waves for controlling the fuel supply means to vary the fuel delivery.

18. A reactive propulsion power plant comprising a tubular shell having a supersonic inlet ram at its forward end, a combustion chamber, and a propulsive nozzle at its rear end, a needle in the inlet shaped to reflect supersonic shock waves to the wall of the inlet, means supporting the needle for axial movement in the inlet, means responsive to the air speed of the power plant for shifting the needle to retain said shock waves in the forward portion of the inlet at various supersonic speeds, means for supplying fuel to the combustion chamber, and means operated by movement of the needle for regulating the fuel supply means.

19. A reactive propulsion power plant comprising a tubular shell having a supersonic inlet ram at its forward end, a combustion chamber, and a propulsive nozzle at its rear end, a needle in the inlet shaped to reflect supersonic shock waves to the wall of the inlet, means supporting the needle for axial movement in the inlet, means responsive to the air speed of the power plant for shifting the needle to retain said shock waves in the forward portion of the inlet at various supersonic speeds, means for supplying fuel to the combustion chamber, and means operated by movement of the needle for regulating the fuel supply means including a constant flow fuel valve.

20. A reactive propulsion power plant comprising a tubular shell having a supersonic inlet ram at its forward end, a combustion chamber, and a propulsive nozzle at its rear end, a needle in the inlet shaped to reflect supersonic shock waves to the wall of the inlet, means supporting the needle for axial movement in the inlet, means responsive to the air speed of the power plant for shifting the needle to retain said shock waves in the forward portion of the inlet at various supersonic speeds, means for supplying fuel to the combustion chamber, a constant flow valve for regulating the fuel supply means and including a seat element, a member in the path of fuel flow having a Venturi passage cooperable with said seat element to restrict the flow, a piston on the Venturi member subjected to the action of said flow, the member being urged toward said element by the flow, and a connection between the needle and member.

21. A reactive propulsion power plant comprising a tubular shell having a supersonic inlet ram at its forward end, a combustion chamber, and a propulsive nozzle at its rear end, a needle in the inlet shaped to reflect supersonic shock waves to the wall of the inlet, means supporting the needle for axial movement in the inlet, means responsive to the air speed of the power plant for shifting the needle to retain the shock waves in the forward portion of the inlet at the various speeds of operation, a pump for supplying fuel to the combustion chamber, a by-pass between the high and low pressure ducts of the pump and having a discharge directed in the downstream direction in said low pressure duct of the pump, and a valve governing said by-pass and operated upon movement of the needle to regulate fuel delivery to the combustion chamber.

22. A reactive propulsion power plant comprising a tubular shell having a supersonic inlet ram at its forward end, a combustion chamber,

and a propulsive nozzle at its rear end, a needle in the inlet shaped to reflect supersonic shock waves to the wall of the inlet, means supporting the needle for axial movement in the inlet, means responsive to the air speed at the power plant for shifting the needle to retain the shock waves in the forward portion of the inlet at the various speeds of operation, a pump for supplying fuel to the combustion chamber, a by-pass between the high and low pressure ducts of the pump, a valve governing said by-pass to regulate the delivery of fuel to the combustion chamber, an operative connection between the needle and valve whereby the valve is operated by needle movement.

23. A reactive propulsion power plant comprising a tubular shell having a supersonic inlet ram at its forward end, a combustion chamber, and a propulsive nozzle at its rear end, a needle in the inlet shaped to reflect supersonic shock waves to the wall of the inlet, means supporting the needle for axial movement in the inlet, means responsive to the air speed at the power plant for shifting the needle to retain the shock waves in the forward portion of the inlet at the various speeds of operation, a pump for supplying fuel to the combustion chamber, a by-pass between the high and low pressure ducts of the pump, a valve governing said by-pass to regulate the delivery of fuel to the combustion chamber, an operative connection between the needle and valve whereby the valve is operated by needle movement, and an overriding control connected with said valve for increasing or decreasing the delivery of fuel to the combustion chamber irrespective of the needle position.

24. A reactive propulsion power plant comprising a tubular shell having a supersonic inlet ram at its forward end, a combustion chamber, and a propulsive nozzle at its rear end, a needle at the inlet shaped to reflect supersonic shock waves to the wall of the inlet, means supporting the needle for axial movement in the inlet, means responsive to the air speed of the power plant for shifting the needle to retain said shock waves in the forward portion of the inlet at various supersonic speeds, means for supplying fuel to the combustion chamber, means responsive to movement of the needle for regulating the fuel supply means, and means for regulating the fuel supply means independently of the position of the needle.

25. In a reactive propulsion engine, a shell having a passage extending therethrough, an inlet ram at the forward end of the passage, a propulsive nozzle at the rear end of the passage, heat generating means in the passage, a member movable in the passage to control the flow of air therethrough, and means responsive to the pressure in the passage at the entrance of the heat generating means and to the pressure adjacent one end of the passage for moving the member.

26. In a reactive propulsion engine, a shell having a passage extending therethrough, one end of the passage being adapted to receive ram air, the other end of the passage being adapted to discharge a propulsive jet of air, heat generating means in the passage, a member movable in the passage to control the flow therein, and motor means for moving the member and responsive to pressures at longitudinally spaced portions of the passage.

27. In a reactive propulsion engine, a shell having a passage extending therethrough, one end of the passage being adapted to receive ram air,

the other end of the passage being adapted to discharge a propulsive jet of air, heat generating means in the passage, a member movable in the passage to control the flow therein, motor means for moving the member, and a control for determining the direction and extent of actuation of the motor means responsive to pressures in the passage at the entrance to the heat generating means and adjacent one end of the passage.

28. In a reactive propulsion engine, a shell having a passage extending therethrough, one end of the passage being adapted to receive ram air, the other end of the passage being adapted to discharge a propulsive jet of air, heat generating means in the passage, a member movable in the passage to control the flow therein, cylinder and piston means for moving the member, and control means responsive to pressures in the passage adjacent one end thereof and adjacent the entrance of the heat generating means for controlling the direction and extent of operation of said cylinder and piston means.

29. A reactive propulsive unit comprising a tubular shell having an inlet ram at its forward end comprising an annular convergent-divergent diffuser, the shell having an intermediate combustion chamber and a propulsive nozzle at its rear end, a substantially central island stationarily supported in the diffuser, a needle having a closed forward end and an open rear end which shiftably telescopes over the island so that the island constitutes a stationary plunger element and the needle constitutes a movable cylinder element, the needle presenting a forwardly convergent surface for reflecting shock waves toward the wall of the inlet when the unit is traveling at supersonic speeds, means for admitting fluid pressure into the needle to cause the same to move axially of the inlet, and means for varying the pressure in the needle to control the position of the needle.

30. In a reactive propulsion engine, a tubular shell, two elements related for relative axial movement, one an inlet ram at the forward end of the shell, the other a needle arranged substantially centrally in the inlet and operable to reflect supersonic shock waves against the wall of the inlet, the needle presenting an external surface shaped to cause convergence of the shock waves toward the wall of the inlet, and servomotor means sensitive to the location of substantial convergence of said shock waves for moving said elements axially one with respect to the other.

NATHAN C. PRICE.

REFERENCES CITED

The following references are of record in the file of this patent:

UNITED STATES PATENTS

Number	Name	Date
991,230	Noyes	May 2, 1911
1,030,890	Johnson	July 2, 1912
2,191,532	Kinzie et al.	Feb. 27, 1940
2,402,363	Bradbury	June 18, 1946

FOREIGN PATENTS

Number	Country	Date
47,412	France	Jan. 28, 1937
(1st addition to French Patent No. 779,655)		
50,033	France	Aug. 1, 1939
(3rd addition to French Patent No. 779,655)		
544,834	Germany	Feb. 29, 1932