United States Patent [19]

Sharpe

[11] **3,841,090**

[45] **Oct. 15, 1974**

[54] **JET ENGINE METHOD**

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[22] Filed: **June 4, 1973**

[21] Appl. No.: **366,571**

Related U.S. Application Data

[62] Division of Ser. No. 191,627, Oct. 22, 1971, Pat. No. 3,750,400.

[52] **U.S. Cl.** **60/204,** 60/269, 60/39.49, 60/39.52

[51] **Int. Cl.** **F02k 1/14**

[58] **Field of Search** 60/204, 269, 267, 207, 60/39.49, 203, 39.52, 206

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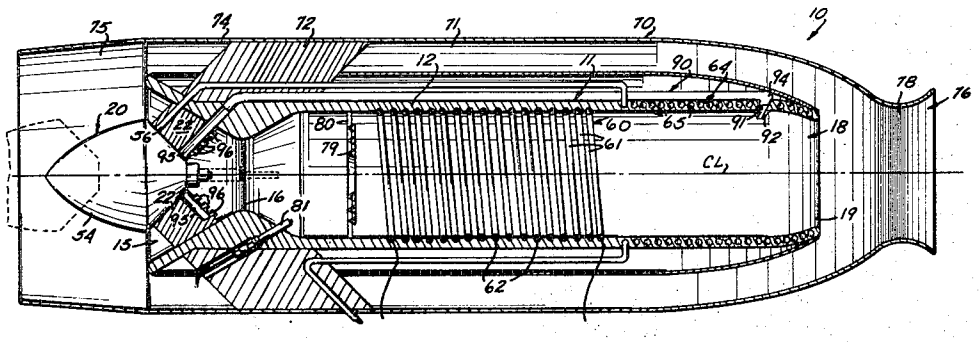
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Primary Examiner—Carlton R. Croyle
Assistant Examiner—Warren Olsen
Attorney, Agent, or Firm—B. J. Powell

[57] **ABSTRACT**

An engine including a self-starting engine compressor unit comprising a burner duct defining a converging-diverging inlet at its forward end, a converging exhaust nozzle at its rear end, and a combustion chamber therebetween; a fuel injection device for injecting fuel under pressure axially through the throat of the inlet into the combustion chmaber to draw air therewith into the chamber; and preheater means for heating the chamber to a predetermined temperature. The compressor unit may include a bypass duct encircling the burner duct with an inlet opening forward of the inlet to the burner duct and a converging exhaust opening rearward of the exhuast nozzle so that air will be drawn through the bypass duct by the jet pumping action of the exhaust gases from the burner duct in combination with the exhaust opening in the bypass duct. The fuel injection device may be equipped with pressure responsive means for transferring the point of injection from forward of the throat of the inlet of the burner duct to a point rearward of the throat and within the combustion chamber. The compressor unit may be embodied in a jet engine as a start stage with intermediate and final ram-jet type stages.

7 Claims, 14 Drawing Figures



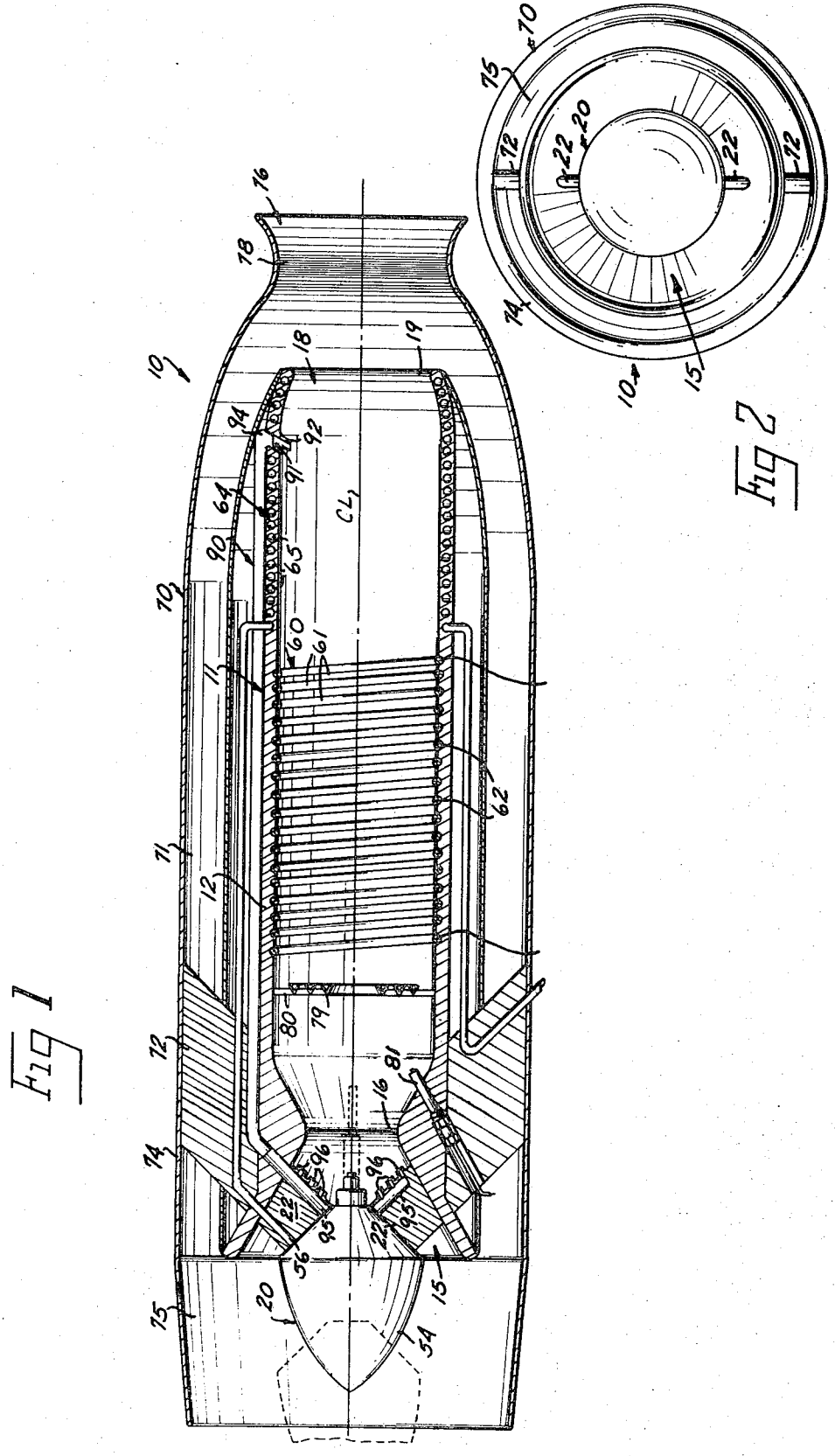

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Fig 1

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Fig 2

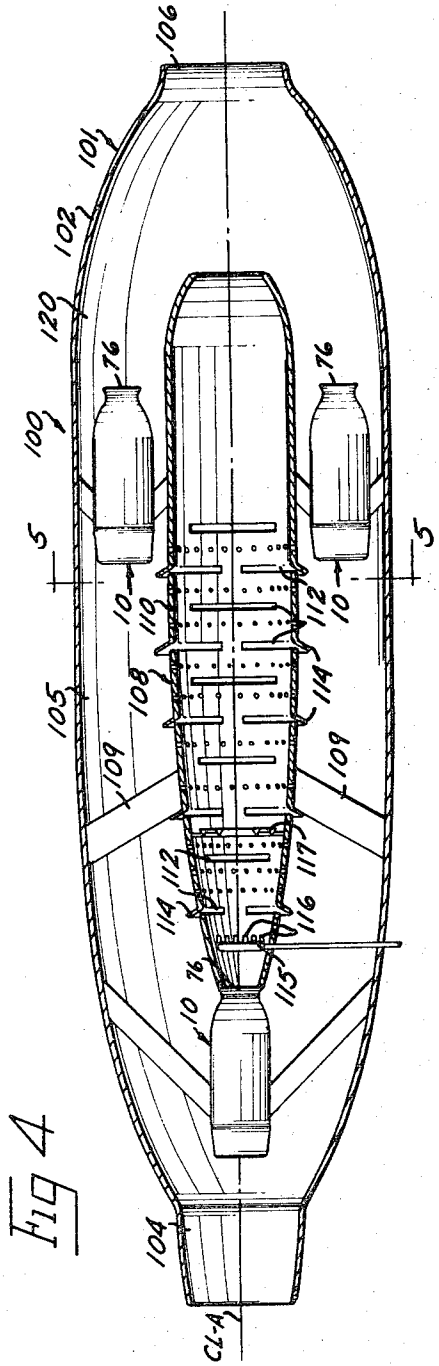


FIG 4

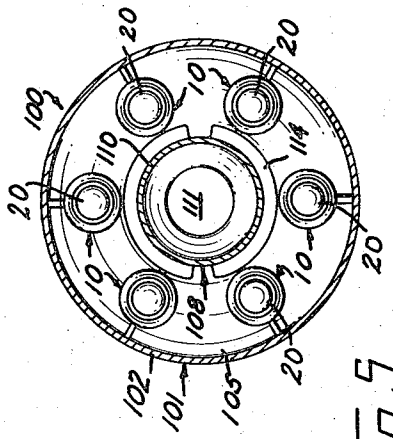


FIG 5

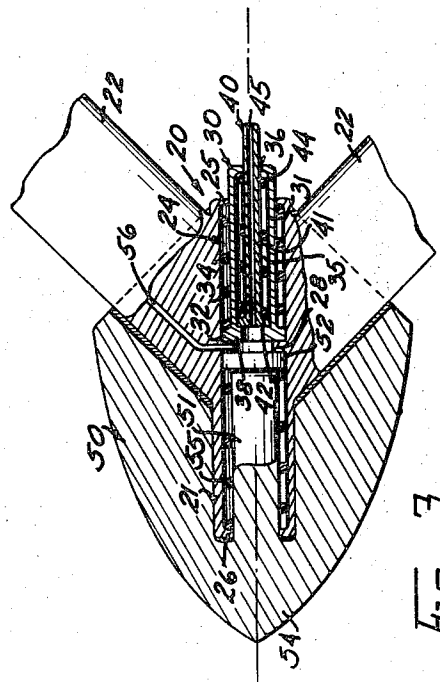


FIG 3

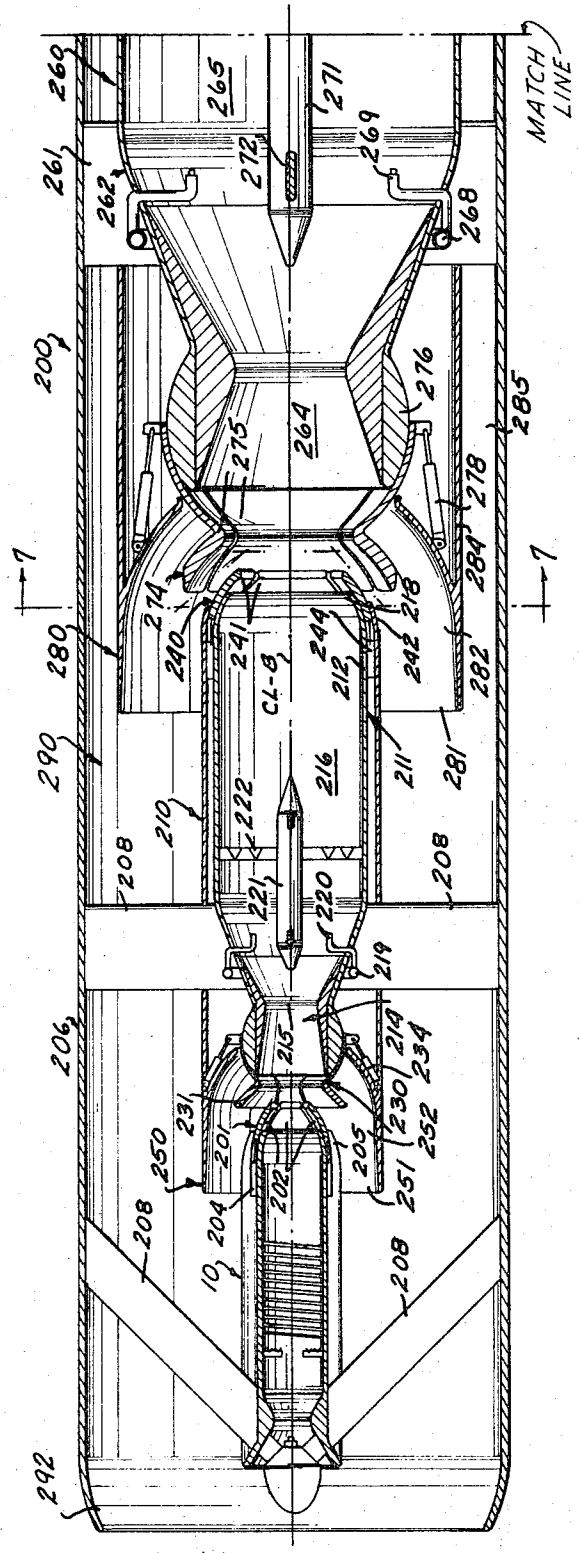

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Fig 6A

FIG 7

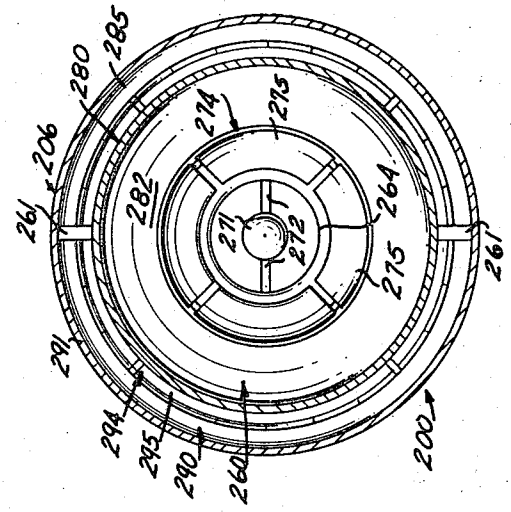
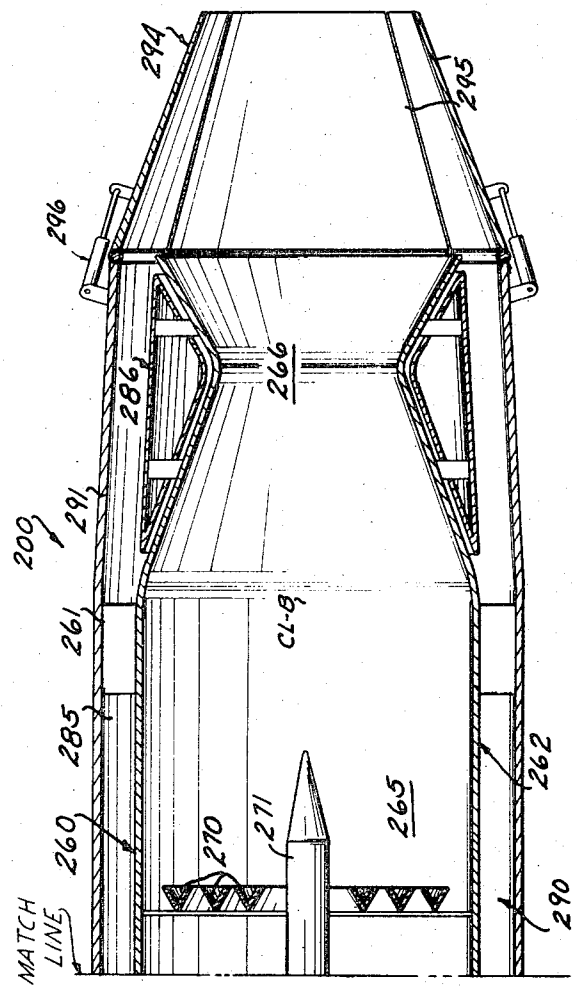

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FIG 6B


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MATCH LINE

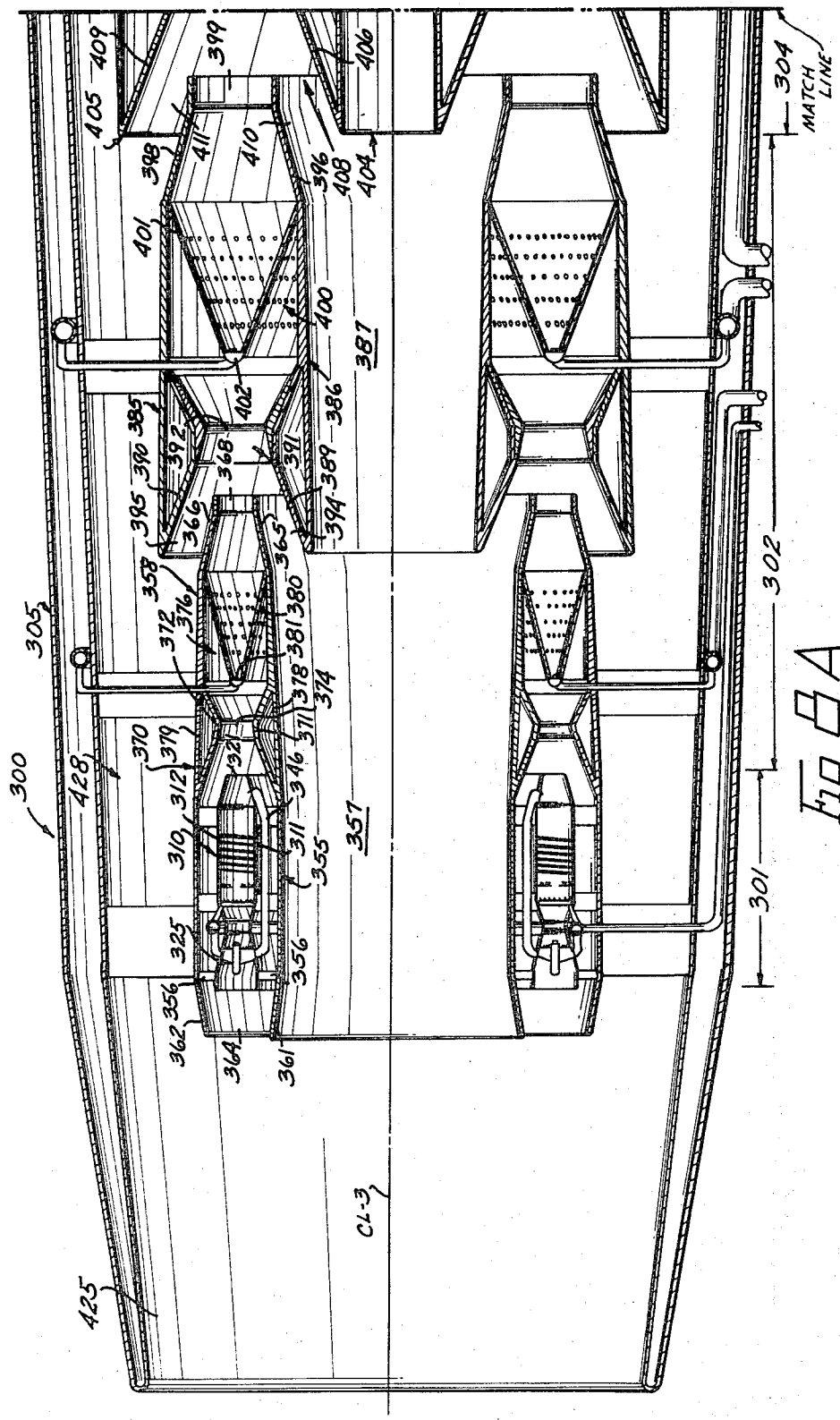

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FIG 8A

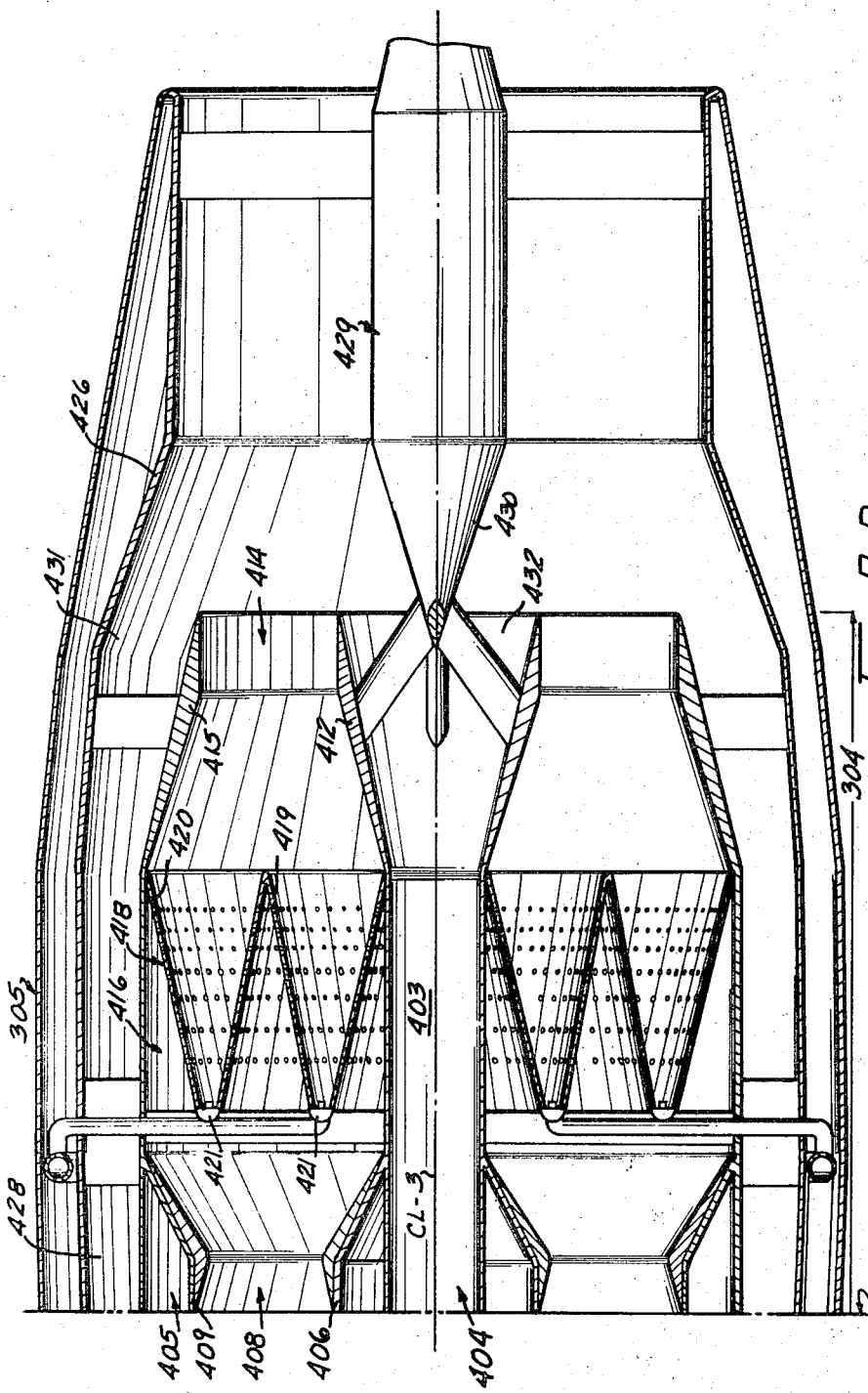

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Fig 8B

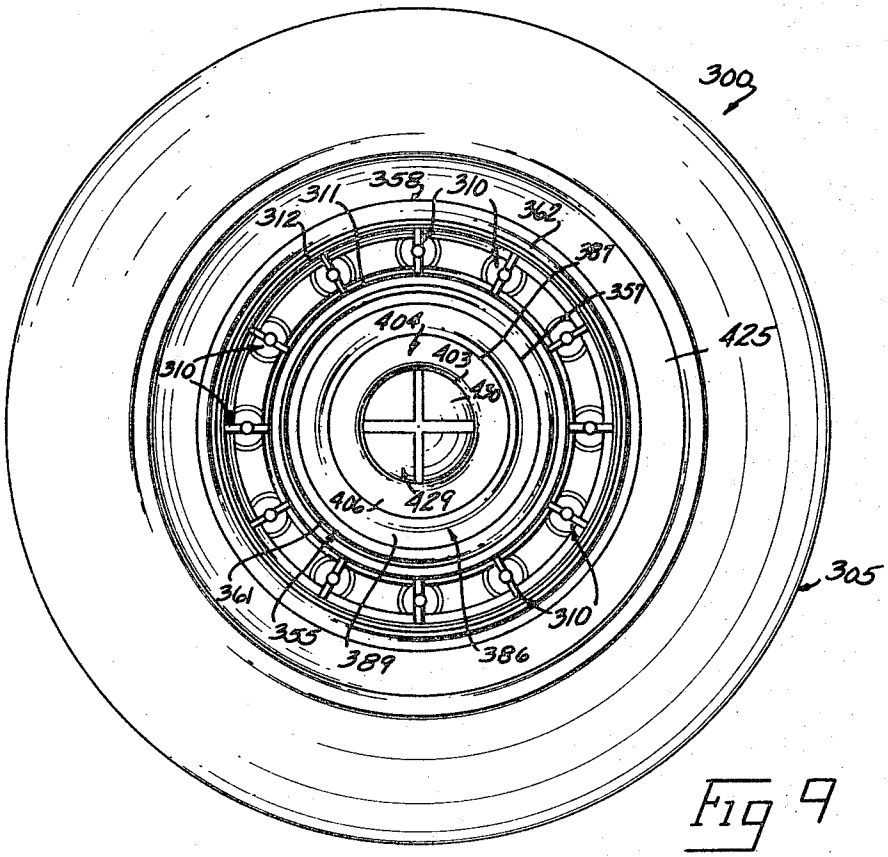

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Fig 9

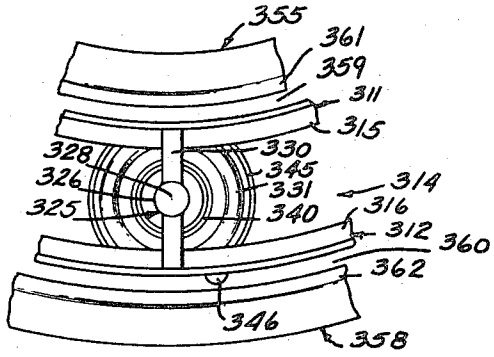

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Fig 11

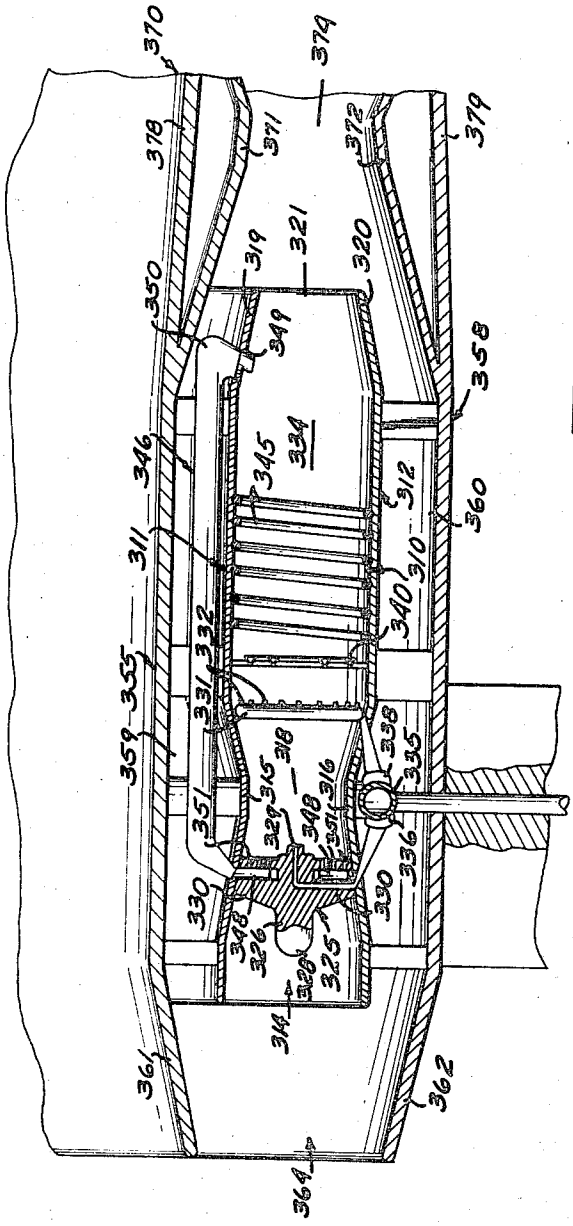

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FIG 10

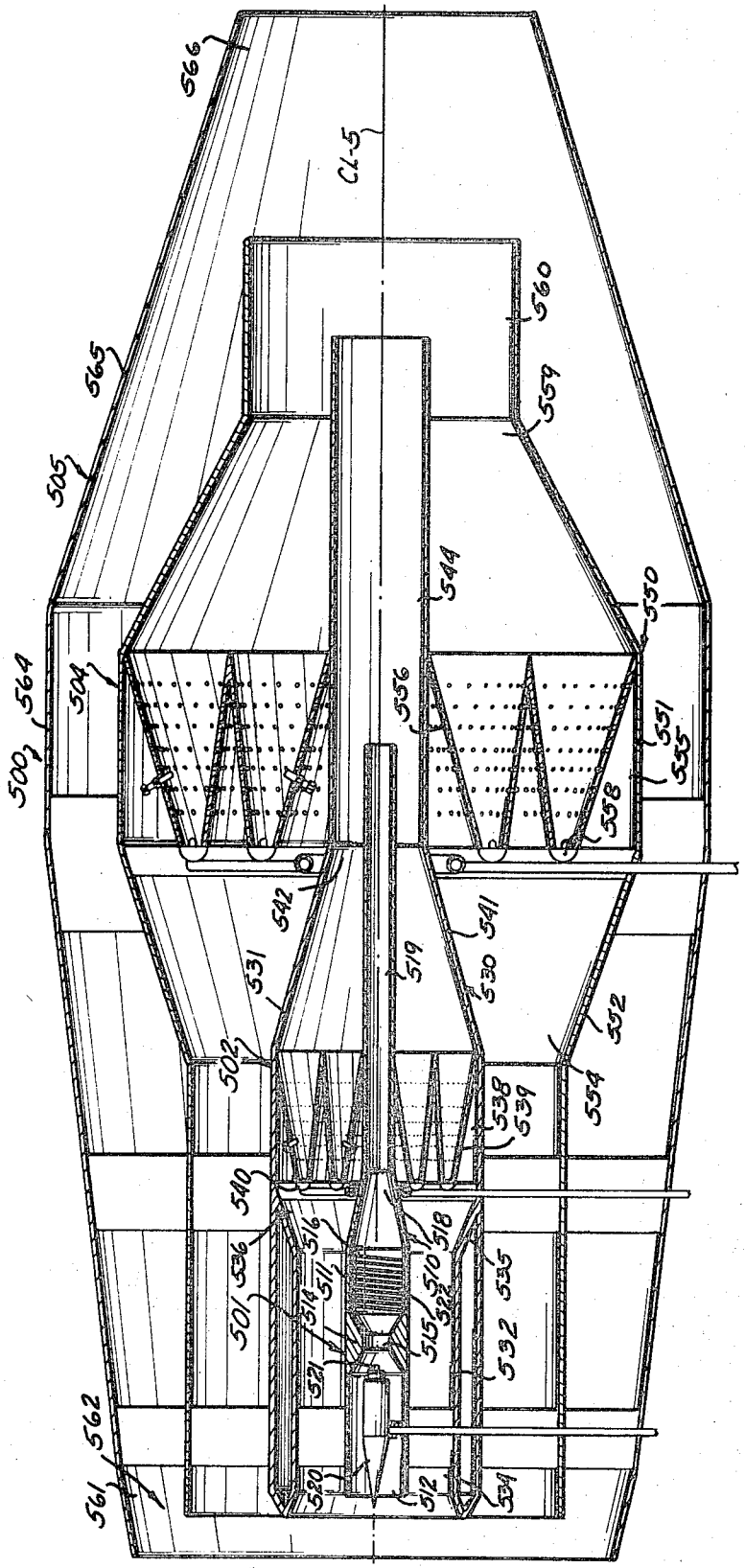

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FIG 12

JET ENGINE METHOD

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a division of my co-pending application Ser. No. 191,627, filed Oct. 22, 1971, now U.S. Pat. No. 3,750,400 for "Engine."

BACKGROUND OF THE INVENTION

Because jet engines must be capable of operating at low plane speeds, currently used engines require a compressor stage for supplying air under pressure to the burner section thereof and a turbine stage driven by the exhaust gases of the burner section to rotate the compressor stage. This requirement for rotating machinery has increased the weigh of the engine as well as limited the maximum temperatures within the engine. Also, the high rotational speed of the rotating parts has required critical dynamic balancing of the parts and extensive maintenance to keep the engine operating properly.

SUMMARY OF THE INVENTION

These and other problems associated with the prior art are overcome by the invention disclosed herein by providing a means for supplying air to the burner section of the engine which requires no rotating parts in the compressor itself or in the engine after the burner section. The invention maintains operation while the engine is stationery or moving at slow speeds. Because of the lack of moving parts, the temperatures within the engine can be raised to produce a more effective operation.

The apparatus of the invention includes a compressor start stage comprising a burner duct including a burner section and an exhaust nozzle, an inlet duct at that end of the burner duct opposite the exhaust nozzle, a fuel injection device for injecting fuel under pressure axially through the reduced diameter throat of the inlet duct and into the burner duct to draw air into the burner section through the inlet duct, and a pre-heater for heating the burner section. The exhaust from the start stage may be injected through the inlet duct of at least one intermediate stage to achieve a jet pump action therethrough and pressurize the burner section of the intermediate stage. Fuel injected into the intermediate stage supports combustion therein and the exhaust therefrom may be injected into the main engine stage to produce combustion and a final thrust.

These and other features and advantages of the invention will become more fully understood upon consideration of the following specification and accompanying drawings wherein like characters of reference designate corresponding parts throughout the several views and in which:

FIG. 1 is an enlarged longitudinal cross-sectional view of one embodiment of the invention;

FIG. 2 is a front view of the start stage of FIG. 7;

FIG. 3 is an enlarged cross-sectional view of the fuel injection head of the start stage of FIG. 1;

FIG. 4 is a longitudinal cross-sectional view showing the embodiment of FIG. 1 installed in an engine;

FIG. 5 is a transverse cross-sectional view taken along line 5—5 in FIG. 4;

FIG. 6A is a longitudinal cross-sectional view of a portion of another embodiment of the invention;

FIG. 6B is a continuation of FIG. 6A showing the rest of the embodiment;

FIG. 7 is a cross-sectional view taken along line 7—7 in FIG. 6A;

FIG. 8A is a longitudinal cross-sectional view of a portion of a second embodiment of the invention;

FIG. 8B is a continuation of FIG. 8A;

FIG. 9 is an inlet end view of the embodiment of FIG. 8A;

FIG. 10 is an enlarged cross-sectional view of one unit of the start stage of FIG. 8A;

FIG. 11 is an inlet end view of FIG. 10; and,

FIG. 12 is a longitudinal cross-sectional view of still another embodiment of the invention.

These figures and the following detailed description disclose specific embodiments thereof, however, it is to be understood that the inventive concept is not limited thereto since it may be incorporated in other forms.

DETAILED DESCRIPTION OF ILLUSTRATIVE EMBODIMENTS

Referring now to FIGS. 1–3, the first embodiment of the invention includes a self-starting jet pump compressor unit **10**. This unit is capable of sustaining combustion at zero forward speed and to produce an increased pressure at its exhaust or pump end.

The unit **10** includes a generally cylindrical burner duct **11** with an annular duct wall **12** forming a substantially constant diameter burner chamber **14** intermediate its ends, a converging-diverging inlet **15** with a reduced diameter throat **16** smaller than the diameter of the burner camber **14** at the front end of duct **16**, and a converging exhaust nozzle **18** at the rear end of duct **11** with a throat **19** of a diameter smaller than that of chamber **14**.

A fuel injection assembly **20** is positioned just forwardly of inlet **15** for injecting fuel through inlet **15** and into chamber **14** axially along the centerline CL of duct **11**. Referring to FIG. **3**, the assembly **20** includes a cylindrical stationary housing **21** concentrically mounted forwardly of inlet **15** by struts **22** attached to duct wall **12**. Housing **21** defines an axially extending cylindrical passage **24** concentric about centerline CL of duct **11**. An inwardly extending annular retaining lip **25** extends around and projects into passage **24** at its rear end and a similar annular retaining lip **26** extends around and projects into passage **24** at its forward end. An annular abutment **28** extends around passage **24** at its central portion.

An intermediate extension tube **30** is slidably received in passage **24** between lip **25** and abutment **28**. Tube **30** includes a cylindrical body **31** of a constant diameter just sufficient to slidably pass through the opening of lip **25** and an annular projecting flange **32** at the forward end thereof just sufficient to slidably move along passage **24** but be retained between abutment **28** and lip **25**. A compression coil spring **34** is received about the body **31** of tube **30** between flange **32** and lip **25** to constantly urge tube **30** toward abutment **28**. A central support passageway **35** axially extends through tube **30** with an annular inwardly extending lip **36** at its rear end and a similar lip **38** at its forward end.

A fuel nozzle tube **40** is slidably received in passageway **35**, and includes a main body portion **41** of constant diameter just sufficient to pass through the opening of lip **36** with an annular outwardly projecting

flange 42 at its forward end sufficient to slidably move in passageway 35 and be retained between lips 36 and 38. A compression coil spring 44 is received about the main body portion 41 between lip 36 and flange 42 to constantly urge tube 40 forwardly against lip 38 in passageway 35. An axially extending fuel passage 45 is defined through nozzle tube 40 which communicates with passage 24 in housing 21 at its forward end and into the burner duct 11 at its rear end.

An inlet spike 50 is slidably mounted about housing 21 and in passage 24 forwardly of abutment 28 and includes a central shaft 51 of a constant diameter just sufficient to slidably pass through the opening defined by lip 26, a disc 52 on the rear end of shaft 51 slidably received in the forward portion of passage 24 and retained between abutment 28 and lip 26, and a conical spike head 54 on the forward end of shaft 51 and extending back over the housing 21. A compression coil spring 55 is received around shaft 51 between disc 52 and lip 26 to constantly urge spike 50 rearwardly toward abutment 28.

A fuel line 56 communicates with passage 24 through abutment 28 and with a pressurized fuel supply source (not shown). In the fully retracted position, the rear end of the intermediate extension tube 30 is substantially flush with the rear end of housing 21 and the discharge end of the nozzle tube 40 is positioned axially within the inlet 15 forward of its throat 19 so that fuel discharged from fuel passage 45 will be injected axially through throat 19 into the burner chamber 14. The spike head 54 is fully retracted rearwardly over housing 21 and about struts 22. The operation of the assembly 20 will be explained in more detail hereinafter.

A preheater assembly 60 is mounted in the burner chamber 14 for preheating same prior to injection of fuel therein in order to start unit 10. Assembly 60 may be any of a number of available preheating means and is shown as a heating coil 61 carried within appropriate recesses 62 around the inside of duct wall 12 at the burner chamber. This allows substantially unrestricted passage of the combustion medium through chamber 14. Coil 61 is connected to an appropriate power source (not shown) to heat same as will be explained.

Fuel line 56 is connected to the pressurized fuel supply source through a heat transfer section 64 located in duct wall 12 at the exhaust nozzle 18 and includes a series of passages 65 in duct wall 12. The fuel passes through the passage 65 on its way to the fuel injection assembly 20 to be heated while at the same time cooling the duct wall 12.

A by-pass duct 70 is concentrically located about the burner duct 11 and defines a central opening 71 therethrough into which the duct 11 is positioned on struts 72. The duct wall 74 defines a diverging inlet 75 just forward of the inlet 15 of duct 11 and a converging-diverging outlet 76 just rearwardly of exhaust nozzle 18. As combustion takes place within burner chamber 14, the discharging exhaust gases from the exhaust nozzle 18 pass through the reduced diameter throat 78 of outlet 76 to cause air to be drawn into inlet 75 by a jet pump effect.

In order to retain the combustion within the burner chamber 14, conventional flame holders 79 are concentrically mounted in burner chamber 41 rearwardly of the throat 16 of inlet 15. The flame holders 79 are carried by mounting bars 80 attached to duct wall 12 of the duct 11. Igniter plugs 81 may be provided to start combustion.

A feedback bleed tube 90 may be fitted to the duct 11 and provided with an inlet 91 at the converging section of exhaust nozzle 18. A forwardly facing scoop 92 is provided within duct wall 12 to direct a small portion of the high velocity exhaust gases into a pressure reservoir 94 in tube 90. The trapped gases pressurize the tube 90 and travel forwardly along tube 90 to a manifold 95 in struts 22 to pressurize same. The gases then pass from manifold 95 back into inlet 15 through nozzles 96 to force more air into chamber 14.

OPERATION

In operation, power is first supplied to the preheater assembly 60 to heat the air within the burner chamber 14 to the approximate ignition temperature of the fuel. This also heats the fuel within the heat transfer section 64 so that it will be substantially completely vaporized when it leaves the passage 45 in fuel nozzle tube 40. When the appropriate temperature is reached, the fuel supply injects the fuel through the passage 24 and out of the fuel passage 45 through the throat 16 of inlet 15 and into the heated air in the burner chamber 14. The igniter plugs 81 are powered in conventional manner so that as the incoming high velocity fuel stream mixes with the air combustion takes place. At the same time, the incoming fuel stream draws more air into burner chamber 14 to pressurize same and supply more air to support combustion. The preheater assembly 60 and igniter plugs 81 are then de-powered and the combustion is self-sustaining. It is to be understood that the preheater assembly 60 may be integrated with the heat transfer section 64 or that the fuel may be preheated before it reaches the section 64 and this heat used to heat chamber 14 without or in combination with the assembly 60.

As the exhaust gases exit through the exhaust nozzle 18 of duct 11, they pass through the throat 78 of outlet 76 to create a suction at the inlet 75 to draw additional air into unit 10 to further pressurize the burner chamber 14.

Since the unit 10 is designed for use as a compressor stage in a jet engine as will be described, the fuel injection assembly 20 is provided with means for moving the point of injection of the fuel from forward of throat 16 to a position behind the throat in burner chamber 14 when the pressure within the burner chamber 14 due to the ram effect from the velocity of the unit is sufficient to support combustion. This is provided by increasing the pressure of the fuel being supplied in response to ram pressure to a point where the intermediate extension tube 30 and fuel nozzle tube 40 are fully extended against the force of springs 34 and 44 as seen by dashed lines in FIG. 1. This converts unit 10 into a ram jet. At the same time, the spike 50 is moved forwardly as shown by dashed lines in FIG. 1 to open up the inlet 15 and allow more air to enter the unit 10. When the incoming air to inlet 15 becomes supersonic, spike head 54 of inlet spike 50 also generates a shock wave ahead of the inlet 15 to increase the static pressure.

The fuel nozzle tube 50 may also be equipped with multiple nozzles, each directing a stream of vaporized fuel substantially axially through the throat 16 of inlet 15 in lieu of the single fuel passage 45. This allows more fuel to be injected into the burner chamber 14

while at the same time generating enough jet pumping effect to force the necessary additional air into chamber **14** to support combustion and provide the necessary mixing of fuel and air.

ENGINE INSTALLATION

As seen in FIGS. **4** and **5**, units **10** are installed in an engine **100** to provide sufficient pressure within the engine to operate same even when the engine is stationary. Engine **100** has a main duct tube **101** having an annular side wall **102.** Wall **102** defines a diverging inlet opening **104** with a main burner chamber **105** of increasing diameter thereafter and terminating in a converging outlet **106.** A tapered burner can **108** is concentrically located within chamber **105** by struts **109** between the side wall **102** of tube **101** and the can wall **110** of burner can **108.** The rear end of can wall **110** forms a converging exhaust nozzle **111** which discharges through the larger diameter outlet **106.** Burner can **108** is provided with dircumferentially extending slots **112** with forwardly facing air scoops **114** along the rear endges of slots **112** as will be explained.

The smaller forwardly facing end of burner can **108** joins with the rear end of a compressor unit **10** so that the exhaust gases and air discharged through the outlet **76** of unit **10** moves axially rearwardly along the centerline CL-A of the engine **100** and burner can **108.** An annular fuel manifold **115** is positioned in burner can **108** behind the outlet **76** of unit **10** and is provided with rearwardly facing nozzles **116** of conventional design for spraying the fuel into can **108.** Flame holders **117** may be provided in can **108** to retain the flame.

A plurality of units **10** are positioned in the annular passage **120** between the burner can **108** and side wall **102** of duct tube **101** near the rear end of the can **108.** The units **10** are equally spaced circumferentially about can **108** so that the exhaust gases and air discharged from each of their outlets **76** are directed through the converging outlet **106** of duct tube **101** to draw air moving along the annular passage **120** into the burner can **108.**

In operation, the units **10** are ignited as set forth hereinabove to draw air into the inlet opening **104.** The unit **10** in front of the burner can **108** discharges the air-exhaust gas mixture therefrom axially along the burner can **108** while the remaining units **10** discharge the air-exhaust gas mixture through the outlet **106** to draw air along the annular passage **120.** The forwardly facing air scoops **114** direct a portion of the air from passage **120** into the interior of can **108** and the jet pumping action of the discharging air-exhaust gas mixture also draws additional air into the burner can **108.**

After the units **10** are operating, fuel is supplied to manifold **115** and discharged rearwardly by nozzles **116** where it is mixed with the air and exhaust gas mixture within burner can **108** and ignited by the heat of the exhaust gases from the forward unit **10** and combustion is sustained for the engine **100** to produce thrust.

SECOND ENGINE INSTALLATION

Referring to FIGS. **6A–7**, the unit **10** is incorporated in an engine **200** of the axial flow type. The unit **10** has the by-pass duct **70** removed therefrom and is equipped with a variable throat exhaust nozzle assembly **201.** Assembly **201** includes a plurality of arcuate vanes **202** slidably positioned about the nozzle **18** of duct **11** and selectively positioned by a plurality of fluid cylinders **204.** An appropriate guide **205** is provided to cause the vanes **202** to pass along the duct wall **12** to selectively throttle the exhaust gases being discharged from the burner chamber **14** as will be explained.

The unit **10** is concentrically mounted in the forward end of a cowling tube **206** described below by a pair of mounting struts **208.** Mounted rearwardly of the unit **10** concentrically in tube **206** is an intermediate stage **210** carried by struts **208.**

The intermediate stage **210** is aligned with the discharging exhaust gases from unit **10** and receives additional air from the jet pump arrangement at the forward end thereof to support combustion therein. Stage **210** includes a main tube **211** with an annular tube wall **212** concentrically located about the centerline CL-B of engine **200.** Tube **211** defines a converging-diverging inlet **214** at its forward end spaced rearwardly of the vanes **202** on unit **10.** The diameter of the throat **215** of inlet **214** is larger than the maximum opening provided by vanes **202.**

Rearwardly of inlet **214** wall **212** defines a combustion chamber **216** and the rear end of tube **210** defines a converging exhaust opening **218.** A fuel manifold **219** is positioned around the outside of tube wall **212** at the forward end of combustion chamber **216** with a plurality of fuel nozzles **220** of conventional design protruding through the tube wall **212** into the combustion chamber **216.** An inlet spike **221** may be mounted in the forward end of combustion chamber **216** to act as a diffuser section within chamber **216** especially at supersonic air-exhaust gas mixture flow rates through the throat **215** of inlet **214.** Flame holders **222** may be provided aft of the fuel nozzles **220** to maintain the flame within combustion chamber **216.**

A throttling assembly **230** complimentary to the assembly **201** of unit **10** is provided forward of inlet **214.** Assembly **230** includes a plurality of movable vanes **231** around inlet **214** to define a converging-diverging opening. Vanes **231** are carried by the forward end of tube wall **212** and selectively positioned by a plurality of fluid cylinders **234** so as to vary the annular opening between vanes **202** and the converging walls **235** of vanes **231.** This serves to vary the amount of air pumped through the inlet **214** of stage **210** by the jet pumping action of the exhaust from unit **10.**

A variable throat exhaust nozzle assembly **240** is provided about the exhaust opening **218** of tube **211.** The nozzle assembly **240** is similar in construction to the nozzle assembly **201** with a plurality of arcuate vanes **241** slidably mounted in guide **242** and positioned by cylinders **244** so as to vary the discharge opening of stage **210** and throttle the exhause therefrom.

A generally semi-circular cowling **250** is provided about the throttling assembly **230** with its open mouth **251** extending over the rear end of unit **10** to provide an air metering apssage **252** into the inlet **214** of stage **210.**

A main thrust stage **260** is mounted within cowling tube **206** rearwardly of intermediate stage **210** by struts **261** and aligned with the discharging exhaust gases from unit **10.** Additional air is supplied thereto by the jet pump arrangement at the forward end thereof to support combustion therein.

The main thrust stage **260** is similar in construction to the intermediate stage **210** except larger with a main thrust tube **262** having a converging-diverging inlet **264**, combustion chamber **265**, and a converging-diverging exhaust outlet **266**. A fuel manifold **268** encircles the outside of tube **262** and has a plurality of conventional fuel nozzles **269** projecting into combustion chamber **265**. A plurality of flame holder rings **270** are positioned in chamber **265** and an inlet spike **271** is mounted on struts **272** in the forward end of combustion chamber **265** to act as a diffuser section in chamber **265**, especially at supersonic air-exhaust gas mixture flow rates through inlet **264**.

A throttling assembly **274** similar to assembly **230** and complimentary to the exhaust nozzle assembly **240** at the rear end of intermediate stage **210** is provided on the forward end of tube **262**. The assembly **274** cooperates with assembly **240** similarly to the co-operation between assembly **230** and assembly **201** to selectively throttle the amount of air drawn through the inlet **264** of the main thrust stage **260** by the jet pumping action of the exhaust gases discharged by intermediate stage **210**. Assembly **274** includes a plurality of movable vanes **275** around inlet **264** to form a converging-diverging opening and slidably mounted on guide **276**. A plurality of fluid cylinders **278** control the position of the vanes **275**.

A generally semi-circular cowling **280** is provided about the throttling assembly **274** similarly to cowling **250** of intermediate stage **210**. The forwardly facing open mouth **281** of cowling **280** extends over the rear end of stage **210** to provide an air metering passage **282** into the inlet **264** of the main thrust stage **260**. The cowling **280** includes an cylindrical annular outer wall **284** which extends rearwardly from mouth **281** to join with the thrust tube **262** at its combustion chamber. This provides an annular by-pass duct **285** around the main thrust stage **260** as will be explained.

A cooling ring assembly **286** is positioned around the reduced diameter portion of tube **262** at the exhaust outlet **266** to direct a portion of the air from the by-pass duct **285** along the outer surface of tube **262** and cool same.

The cowling tube **206** defines the outside of the engine and mounts the compressor unit **10**, intermediate stage **210** and main thrust stage **260** in its central cavity **290**. Tube **206** has an annular cylindrical side wall **291** which projects forwardly of the unit **10** to provide a diverging inlet duct **292** forwardly of unit **10** and terminates substantially in the same plane as the exhause outlet **266** of the main thrust stage **260**.

A flap-type augmentated exhaust nozzle assembly **294** is mounted on the rear end of cowling tube **206**. Assembly **294** includes a plurality of flaps **295** hinged to the tube **206** and positioned by fluid cylinders **296** in known manner. The varying of the position of flaps **295** serves to control the amount of by-pass air drawn through duct **285** by the jet pumping action of the exhaust from the main thrust stage **260**.

OPERATION OF SECOND ENGINE INSTALLATION

In operation, the compressor unit **10** is ignited as set forth hereinabove. Its exhaust gases are injected axially through the inlet **214** of intermediate stage **210** which creates a jet pumping action to draw additional air into stage **210** through the annular metering opening defined between vanes **202** and **231** and also to draw additional air into the inlet **15** of unit **10**. The jet pumping action of unit **10** pressurizes the burner chamber **216** of stage **210**.

When fuel is sprayed into the chamber **216** by nozzles **220**, ignition takes place because of the heat from the exhaust gases of unit **10** and operation of the intermediate stage **210** starts. The discharging exhaust gases from stage **210** are injected through the inlet **264** of the main thrust stage **260**. This causes air to be drawn into the stage **260** through the annular opening between vanes **241** and **275** to pressurize the burner chamber **265** thereof. When fuel is supplied via nozzles **269** to chamber **65**, ignition takes place from the heat of the exhaust gases of stage **210**. The exhaust gases from stage **260** discharging through the nozzle assembly **294** causes additional air to be drawn into the engine via the inlet duct **292** to further pressurize the engine.

Because control systems for controlling the amount of fuel injected into the engine **200** as well as the position of the assemblies **201, 230, 240, 274** and **294** are available, these controls are not described. It will be seen that the jet pumping action of each stage is summed, sufficient operating pressure is maintained within the engine.

THIRD ENGINE INSTALLATION

Referring now to FIGS. **8A–10**, the invention is embodied in engine **300** having a compressor stage **301**, an intermediate stage **302**, and a main thrust stage **304**.

Engine **300** includes a main cowling tube **305** which mounts the various engine stages therein. The compressor stage **301** includes a plurality of compressor units **310** positioned within the forward portion of tube **305** and equally spaced concentrically about the centerline CL-3 of engine **300**. The compressor units **310** are mounted between an inner tube ring **311** and an outer tube ring **312** concentrically located with respect to each other and to the centerline CL-3 to form a compressor annulus **314** therebetween. An outwardly projecting bend **315** is formed in inner ring **311** just inwardly of its forward end and, in conjunction with a complementary inwardly projecting bend **316** formed in outer ring **312**, forms an annular throat **318** between the rings **311** and **312**. The rear end of inner ring **311** is angled outwardly to form a nozzle flange **319** and in conjunction with the inwardly angled complementary flange **320** of outer ring **312**, forms an annular exhaust nozzle **321** between rings **311** and **312**. The rings **311** and **312** are arranged so that the throat **318** is axially aligned with exhaust nozzle **321**.

Each unit **310** as best seen in FIGS. **10** and **11** includes a primary fuel metering assembly **325** positioned in the converging portion of annulus **314** forwardly of the throat **318** thereof. Assembly **325** has a cylindrical body **326** with a forwardly facing projection **328** extending toward the inlet of annulus **314** and a rearwardly facing low pressure fuel nozzle **329** for injecting fuel axially through the throat **318** as will be explained. Unit **310** is mounted by struts **330** connected to rings **311** and **312**. Positioned rearwardly of throat **318** in alignment with assembly **325** is a ring manifold **331** having a plurality of rearwardly facing fuel nozzles **332** in the forward end of the annular combustion chamber **334** defined by rings **311** and **312**.

Each nozzle 329 and ring manifold 331 is supplied fuel from a distribution manifold 335 extending around the outside of the ring 312 within bend 316. Each nozzle 329 is connected to manifold 335 through a low pressure bypass valve 336 that restricts fuel flow to the nozzle inversely to the fuel pressure to allow the fuel to flow to nozzle 329 at lower pressure and decrease the flow as pressure increases until the fuel flow is cut off at nozzle 329 when a predetermined fuel pressure is reached. Each ring manifold 331 is connected to manifold 335 through a high pressure bypass valve 338 which allows fuel to flow to ring manifold 331 when the fuel pressure reaches the predetermined pressure at which the fuel flow is cut off to nozzle 329. Flame holders 340 may be positioned in the combustion chamber 334 behind each fuel metering assembly 325 and ring manifold 331 to retain the flame in combustion chamber 334.

A heating coil 345 is placed in the combustion chamber 334 rearwardly of flame holders 340 behind each fuel metering assembly 325 so that preheating as described for unit 10 can take place. This insures starting of each unit 310.

An air bleed tube 346 similar to tube 90 for unit 10 connects the rear end of combustion chamber 334 with a chamber 348 in struts 330. Each tube 346 has a forwardly facing scoop 349 projecting into chamber 334 to direct the gases into a reservior 350 in tube 346. A plurality of rearwardly facing ports 351 in struts 330 inject the gases from chamber 348 through throat 318 to assist in pressurizing combustion chamber 334.

An inner tubular section 335 is positioned inside of ring 311 and concentrically therewith by struts 356 to define an inner bypass 359 between section 355 and ring 311. An outer tubular section 358 is positioned outside of ring 312 and concentrically therewith to define an outer bypass 360 between section 358 and ring 312. An outwardly angled flange 361 is provided at the forward end of section 355 and, in conjunction with an inwardly angled flange 362 on the forward end of section 358, defines a diverging inlet 364 forward of the inlet of the compressor stage 301. The rearmost end of tubular section 355 is provided with an outwardly angled flange 365, which, in conjunction with an inwardly angled flange 366, forms an annular exhaust nozzle 368 for the first power unit 370 of intermediate stage 302.

Just rearwardly of the exhaust nozzle 321 of compressor stage 301, the inner tubular section 355 is provided with an outwardly projecting bend 371, which, in conjunction with a complementary inwardly projecting bend 372 in the outer tubular section 358, forms the inlet 374 of power unit 370 whth throat 375 having a slightly larger opening than that of the exhaust nozzle 321 of compressor stage 301 and axially aligned therewith. This forms an annualr combustion chamber 376 between inlet 374 and exhaust nozzle 368. A ring 378 covers the depression of bend 371 and a ring 379 covers the depression of bend 372 to provide a smooth inner surface along section 355 and a smooth outer surface along section 358.

An annular cone shaped burner shroud liner 380 is positioned in combustion chamber 376 with a plurality of fuel nozzles 381 positioned in the forward end of the liner 380 to supply fuel thereto in conventional manner. The liner 380 serves a a flame holder to retain the combustion flame within chamber 376.

The second power unit 385 of intermediate stage 302 includes an inner tubular section 386 and an outer tubular section 388. The forward ends of sections 386 and 388 project just forwardly of exhaust nozzle 368 of the first power unit and are provided with outwardly and inwardly directed projections 389 and 390 respectively to form an annular converging-diverging inlet 391 with throat 392 axially aligned with the exhaust opening in nozzle 368. Inlet passages 394 and 395 are defined between projection 389 and flange 365 and between projection 390 and flange 366. The rearmost ends of tubular sections 386 and 388 are provided respectively with an outwardly flaring flange 396 and an inwardly flaring flange 398 to form a converging exhaust nozzle 399.

An annular combustion chamber 400 is defined between inlet 391 and exhaust nozzle 399. An annular cone shaped burner shroud liner 401 is positioned in chamber 400 with a plurality of fuel nozzles 402 in the forward ends thereof to supply fuel thereto in conventional manner.

The main thrust stage 304 is positioned rearwardly of the second power unit 385 of intermediate stage 302 and includes an inner tubular section 404 projecting within the flange 396 of unit 385 and an outer tubular section 405 projecting around flange 398 of unit 385. The forward end of section 404 has an inwardly extending projection 406 to form an annular converging-diverging inlet 408 with an inwardly extending projection 409 on the forward end of tubular section 405. An annular inner inlet duct 410 to stage 304 is defined between flange 396 of unit 385 and projection 406 and an annular outer inlet duct 411 is defined between flange 398 of unit 385 and projection 409.

The rearmost end of tubular section 404 has an outwardly flaring flange 412 which forms a diverging exhaust nozzle 414 with an inwardly flaring flange 415 at the rearmost end of tubular section 405. This defines an annular combustion chamber 416 between inlet 408 and exhaust nozzle 414.

A compound burner can assembly 418 is positioned in combustion chamber 416. Can assembly 418 includes an annular cone shaped inner shroud liner 419 and outer shroud liner 420. The forward ends of liners 419 and 420 are provided with fuel nozzles 421 of conventional design to provide fuel to chamber 416.

The main cowling tube 305 defines a diverging inlet duct 425 forwardly of compressor stage 301 and a converging exhaust opening 426 rearwardly of the exhaust nozzle 414 of the main thrust stage 304. Since the cowling tube 305 is larger in diameter than any of stages 301, 302 or 304, a bypass duct 428 is provided along the length of engine 300 outside of stages 301, 302 and 304. A cone member 429 is positioned in the exhaust opening 426 with its forwardly facing tapered end 430 projecting within flange 412. The converging portion of tube 305 at exhaust opening 426 defines a bypass air inlet duct 431 with flange 415 and member 429 defines an inner air inlet duct 432 with flange 412.

OPERATION OF THIRD ENGINE INSTALLATION

Engine 300 is started similarly to engine 200. First, the heating coils 345 are supplied with electricity of heat same. This also heats the air within the annular combustion chamber 334 in the vicinity of each unit 310 to a temperature sufficient to ignite the fuel as with

unit 10. It is also to be understood that coils 345 may extend completely around the rings 311 and 312 to achieve the same result.

When the desired temperature is reached, fuel under pressure is supplied to the low pressure fuel nozzle 329 of each unit 310. The fuel pressure is sufficiently low to not open valves 338 so that no fuel is supplied to chamber 334 from the nozzles 332 of ring manifold 331. The fuel is ejected from the low pressure nozzles 329 small streams at high velocity axially through the throat 318 of annulus 314 and into combustion chamber 334. This causes air to be drawn into chamber 334 with the fuel through throat 318 by the jet pumping influence of the fuel. When the fuel reaches the heated air in chamber 334, it ignites to start combustion. The additional fuel and air entering chamber 334 sustains the combustion once it has started and the heat of combustion maintains the proper operating temperature in the chamber 334 thus allowing the coils 345 to be shut off.

The exiting exhaust gases from the exhaust nozzle 321 pumps additional air into the combustion chamber 376 of the first power unit 370 via the inlet 364, bypasses 359 and 360, and throat 375 of inlet 374 because of the jet pumping action of the gases in combination with the throat 375 of unit 370. This also draws additional air into the throat 318 of the compressor stage 301. A portion of the exhaust gases is trapped by the scoops 349 of the units 310 to pressurize the bleed tubes 346 and force these gases rearwardly out of ports 351 in struts 330. The jet pumping action of the exiting gases from the ports 351 forces additional air into the combustion chamber 334 to pressurize same and support combustion.

The exhaust gases from the compressor stage 301 passing into the chamber 376 of the first power unit 370 heats same to fuel ignition temperature whereupon fuel is sprayed from nozzles 381 into chamber 376 to start combustion within this unit. The exiting exhaust gases from the nozzle 368 of power unit 370 creates a jet pump effect as it passes through the throat 392 of the second power unit 385 to draw air into the combustion chamber 400 from the central passage 357 of the tubular section 355 and from the bypass duct 428 through the inlet passages 394 and 395 to support combustion. This also draws additional air into the front of engine 300 to further pressurize the inlet to units 310. Once combustion chamber 400 is pressurized, the fuel is sprayed therein by fuel nozzles 402 to start combustion.

The exhaust gases from the second power unit 385 are injected axially through the inlet 408 of the main thrust stage 304 to pressurize same from the jet pump action drawing air through inlet ducts 410 and 411 from the central passage 387 of inner tubular section 386 and from the bypass duct 428. Once the combustion chamber 416 is pressurized, fuel is sprayed therein from fuel nozzles 421 to start combustion.

As the exhaust gases from the main thrust stage 304 passes through the exhaust opening 426 in the cowling tube 305, they exert a jet pumping action drawing air through the bypass duct 428 and the central passage 403 of the tubular section 404 thus drawing more air into the inlet duct 425 and further pressurizing the stages 301, 302 and 304.

When the velocity of the engine 300 with respect to the ambient air is sufficient to sustain combustion pressure from the ram effect, control means (not shown) causes the fuel pressure to the metering assemblies 325 of compressor units 310 to be increased sufficiently to cause the valves 336 to shut off fuel flow to nozzles 329 and to open valves 338 to supply fuel to nozzles 332 since the jet pumping action of units 310 is no longer needed.

FOURTH ENGINE INSTALLATION

Referring now to FIG. 12, the fourth embodiment of the invention is an engine 500 which has a jet pumping action directed from the center of the engine outwardly. Engine 500 includes a compressor stage 501, an intermediate stage 502 and a main thrust stage 504 concentrically mounted about the centerline CL-5 of the main cowling tube 505.

The compressor unit 501 has an open duct 510 centrally located in cowling tube 505 at the forward end thereof. Duct 510 has a tubular wall 511 defining a cylindrical inlet passage 512 and with an annular projection 514 at the rear end of passage 512 defining a throat 515 and a combustion chamber 516 therebehind. Combustion chamber 516 is terminated by the wall 511 converging to form an exhaust nozzle 518 with an elongated cylindrical exhaust duct 519 extending through the intermediate stage 502.

A fuel injection assembly 520 similar to assembly 20 of unit 10 is positioned in inlet passage 512 so that the fuel nozzle 521, in its forward retracted position, is positioned ahead of throat 515 so that the fuel is sprayed axially therefrom through throat 515 into combustion chamber 516 and draws air into the chamber 516 similarly to that described hereinabove. The nozzle 521 may be made to extend through throat 515 similar to the assembly 20 for unit 10.

A preheater coil 522 is positioned in combustion chamber 516 similarly to coil 61 in unit 10. This heats the air in chamber 516 to start combustion.

The intermediate stage 502 includes an open ended duct 530 with a tubular wall 531 positioned concentrically about duct 510 of stage 501. Wall 531 has an inwardly projecting annular section 532 forming a reduced diameter inlet passage 534 around the duct 510 of stage 501 with an outwardly flaring rear end portion 535 in the vicinity of the converging wall 511 at exhaust nozzle 518 to form a diverging inlet 536 to combustion chamber 538. Chamber 538 is provided with a compound annular burner can assembly 539 with fuel nozzles 540 similar to assembly 418 in engine 300.

The duct wall 531 has an inwardly tapering section 541 behind the combustion chamber 538 to form a converging exhaust nozzle 542 with a cylindrical exhaust duct 544 extending through the main thrust stage 504 and concentrically about the duct 519 of stage 501. Duct 519 terminates within duct 544.

The main thrust stage 504 includes a duct tube 550 with a tubular wall 551 extending forwardly to the inlet ends of the stages 501 and 502 and concentrically about the duct tube 530 of stage 502. Wall 551 forms a reduced diameter cylindrical inlet passage about stage 502 with an outwardly flaring section 552 in the vicinity of the tapering section 541 of wall 531 in stage 502 to form a diverging inlet 554 to the combustion chamber 555. This chamber, like chamber 538 of stage 502, is provided with a compound burner can assembly 556 and fuel nozzles 558.

Duct wall **551** tapers inwardly after chamber **555** to form a converging exhaust nozzle **559** and a cylindrical exhaust duct **560** concentric about duct **544.** It will be noted that duct **544** terminates within duct **560.**

The cowling tube **505** has an outwardly flaring inlet wall section **561** extending from the vicinity of the forward end of combustion chamber **555** of stage **504** forward of the inlets to stages **501, 502** and **504** to define a diverging inlet **562.** A cylindrical wall section **564** encircles the combustion chamber **555** of stage **504** and an inwardly tapered wall section **565** joins with the rear end of section **564** to extend past the end of duct **560** of stage **504** and form a converging discharge **566.**

This engine is started similarly to the previous embodiments. The primary jet pumping action is performed by the escaping exhaust gases from the stages **501, 502** and **504** and air is drawn into the engine starting from the inside and moving outwardly.

It is to be further understood that each compressor stage **301** of engine **300** or compressor stage **501** of engine **500** may be equipped with heat transfer means similar to the section **64** for unit **10** to preheat the fuel prior to injection into the engine. Further, it is to be understood that the fuel injection assembly **20** may be interchanged with the assembly **335** without departing form the scope of the inventive concept. Moreover, it is to be understood that any of the engines may be equipped with bypass air throttling means as illustrated for engine **200** and that those engines not having air bleed tubes in the compressor stage may be so equipped. A plurality of bleed tubes may be used in lieu of the tube **90** for unit **10.**

While specific embodiments of the invention have been disclosed herein, it is to be understood that full use of modifications, substitutions, and equivalents may be made without departing from the scope of the inventive concept.

I claim:

1. A method of operating an engine having a first stage including a converging-diverging inlet, a fuel injector movable from a first position to a second position, a combustion chamber, and a converging exhaust opening where the inlet is forward of the combustion chamber and air passing rearwardly through the inlet passes into the combustion chamber and the exhaust gases passing rearwardly from the combustion chamber pass through the exhaust opening comprising the steps of:

a. heating the air within the combustion chamber to a predetermined temperature; and,

b. injecting fuel into the combustion chamber alternatively from the first position rearwardly and axially through the inlet into the combustion chamber to cause air to be induced through the inlet into the combustion chamber due to the jet pumping action of the injected fuel, and from the second position rearwardly of the inlet.

2. The method of claim **1** further including the step of redirecting a portion of the exhaust gases in the combustion chamber rearwardly through the inlet to force additional fresh air into the combustion chamber by jet pumping action.

3. The method of claim **1** wherein the engine includes a plurality of subsequent stages, each subsequent stage comprising a converging-diverging inlet, a combustion chamber and a converging exhaust opening further comprising the steps of:

arranging each of the subsequent stages in axial alignment successively with each other and with the first stage;

directing the exhaust gases from the exhaust opening in the first stage axially through the inlet of the nearest subsequent stage to force additional fresh air into the combustion chamber of that stage;

injecting fuel into the combustion chamber of the nearest subsequent stage to support combustion;

directing the exhaust gases from each of the subsequent stages axially through the inlet of the next successive subsequent stage to force additional fresh air into that stage; and,

injecting fuel into the combustion chamber of each of the subsequent stages to support combustion.

4. The method of claim **3** further comprising the step of selectively varying the effective size of each exhaust opening of the first and subsequent stages.

5. The method of claim **3** further comprising the step of selectively varying the amount of fresh air forced into the combustion chamber of each of the subsequent stages.

6. The method of claim **1** wherein the engine includes a plurality of subsequent stages, each subsequent stage comprising an inlet, a combustion chamber and an exhaust duct further comprising the steps of:

discharging the exhaust gases from the first stage rearwardly in the exhaust duct of the first of the subsequent stages to draw air through the inlet into the combustion chamber of the first of the subsequent stages by jet pumping action;

discharging the exhaust gases from the subsequent stages into the exhaust duct of the next subsequent stage to draw air through the inlet into the combustion chamber of that subsequent stage; and,

injecting fuel into the combustion chamber of each of the subsequent stages to support combustion.

7. The method of claim **1** wherein the step of injecting the fuel includes causing the injection of the fuel to transfer from said first position to said second position in response to a predetermined forward velocity of the engine through the ambient air.

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