Nov. 17, 1953 F. E. NULL 2,659,202

AUGMENTED THRUST PULSE JET PUMP OR MOTOR AND METHOD OF CREATING AUGMENTED THRUST OR SUCTION

Filed June 6, 1950 11 Sheets-Sheet 1

Fig.1

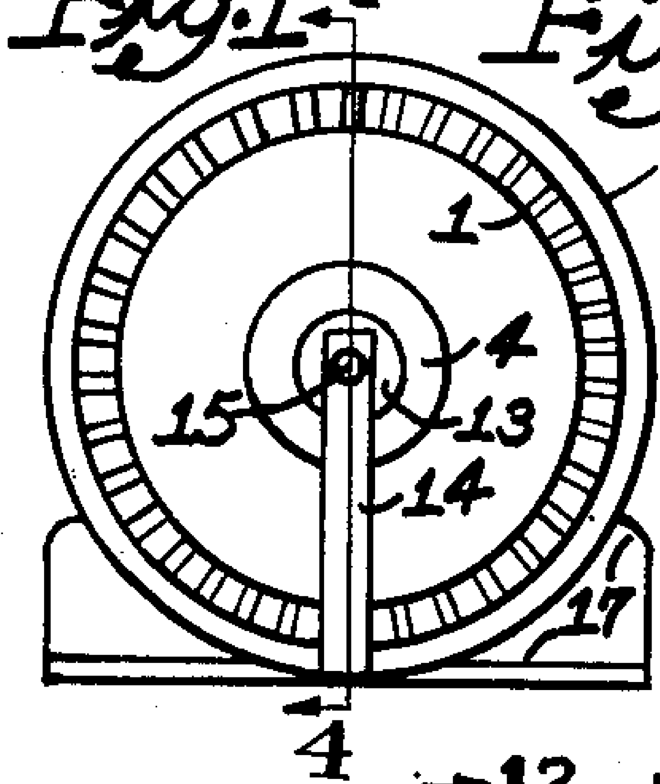


Fig.2

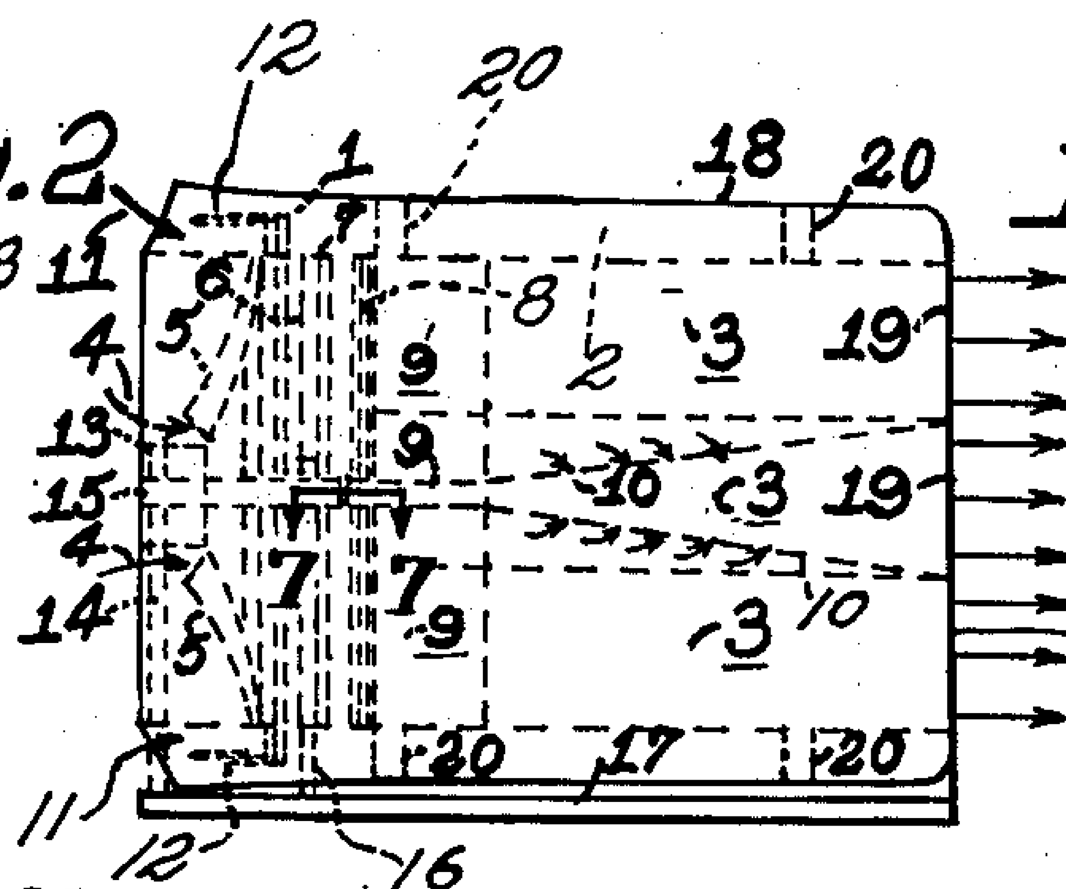


Fig.3

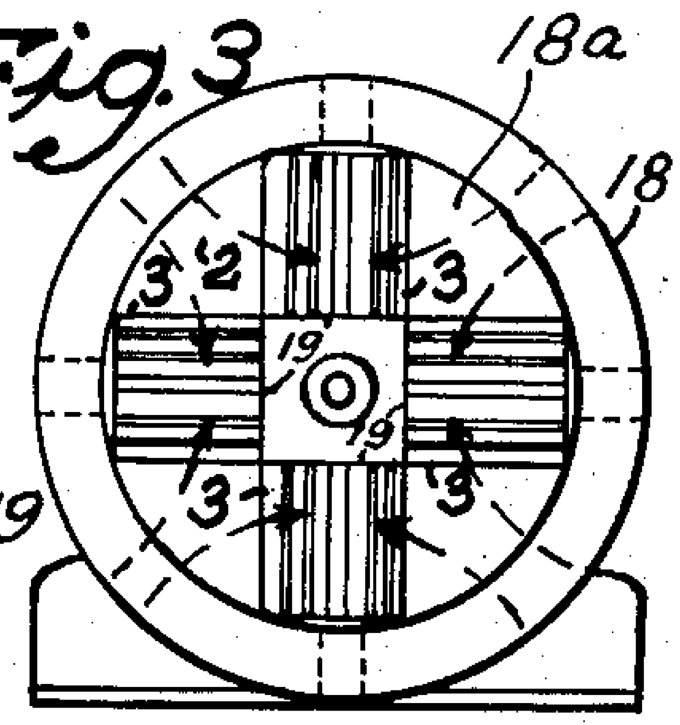
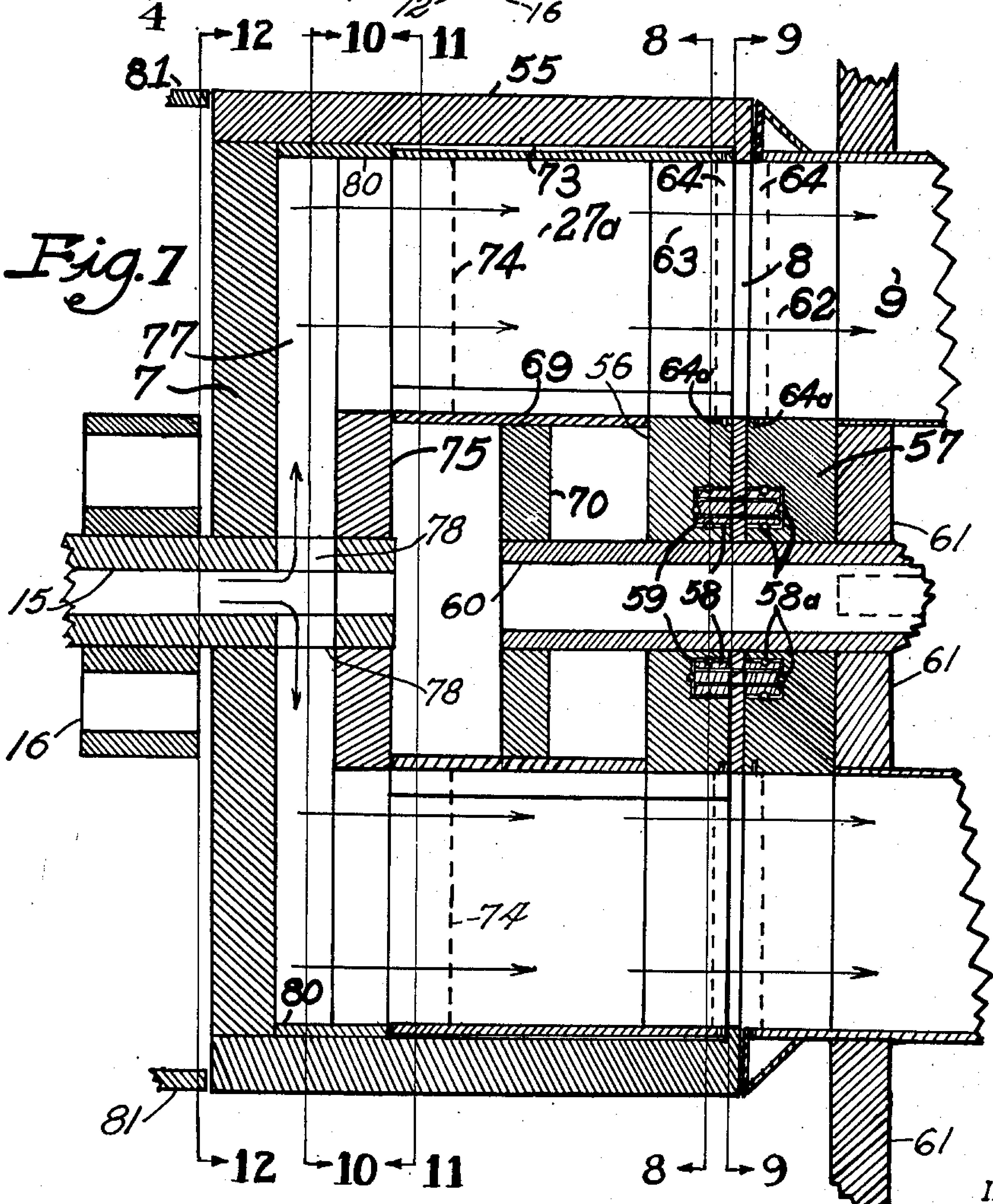


Fig.7



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AUGMENTED THRUST PULSE JET PUMP OR MOTOR AND METHOD OF CREATING AUGMENTED THRUST OR SUCTION

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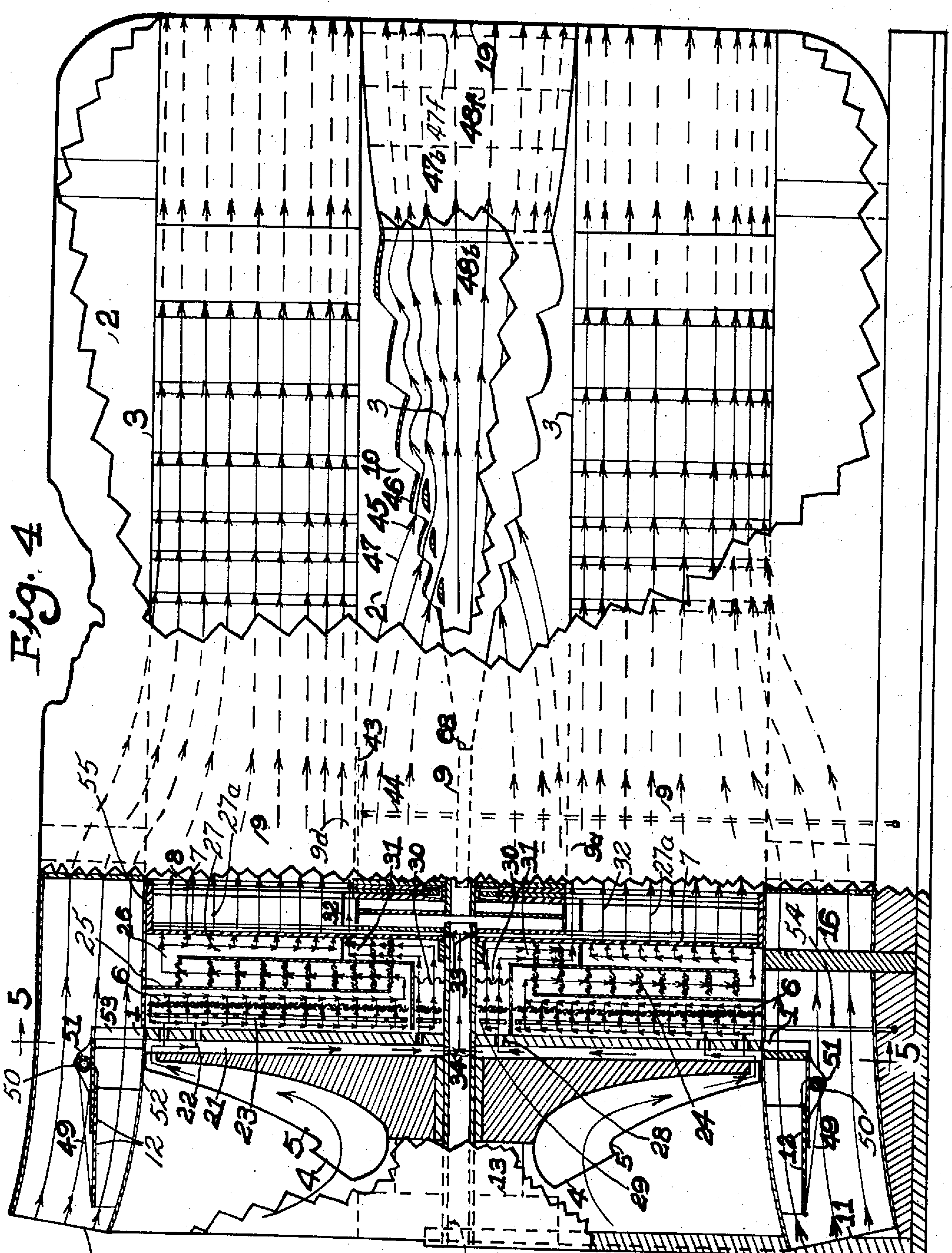

Fig. 4

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AUGMENTED THRUST PULSE JET PUMP OR MOTOR AND METHOD
OF CREATING AUGMENTED THRUST OR SUCTION
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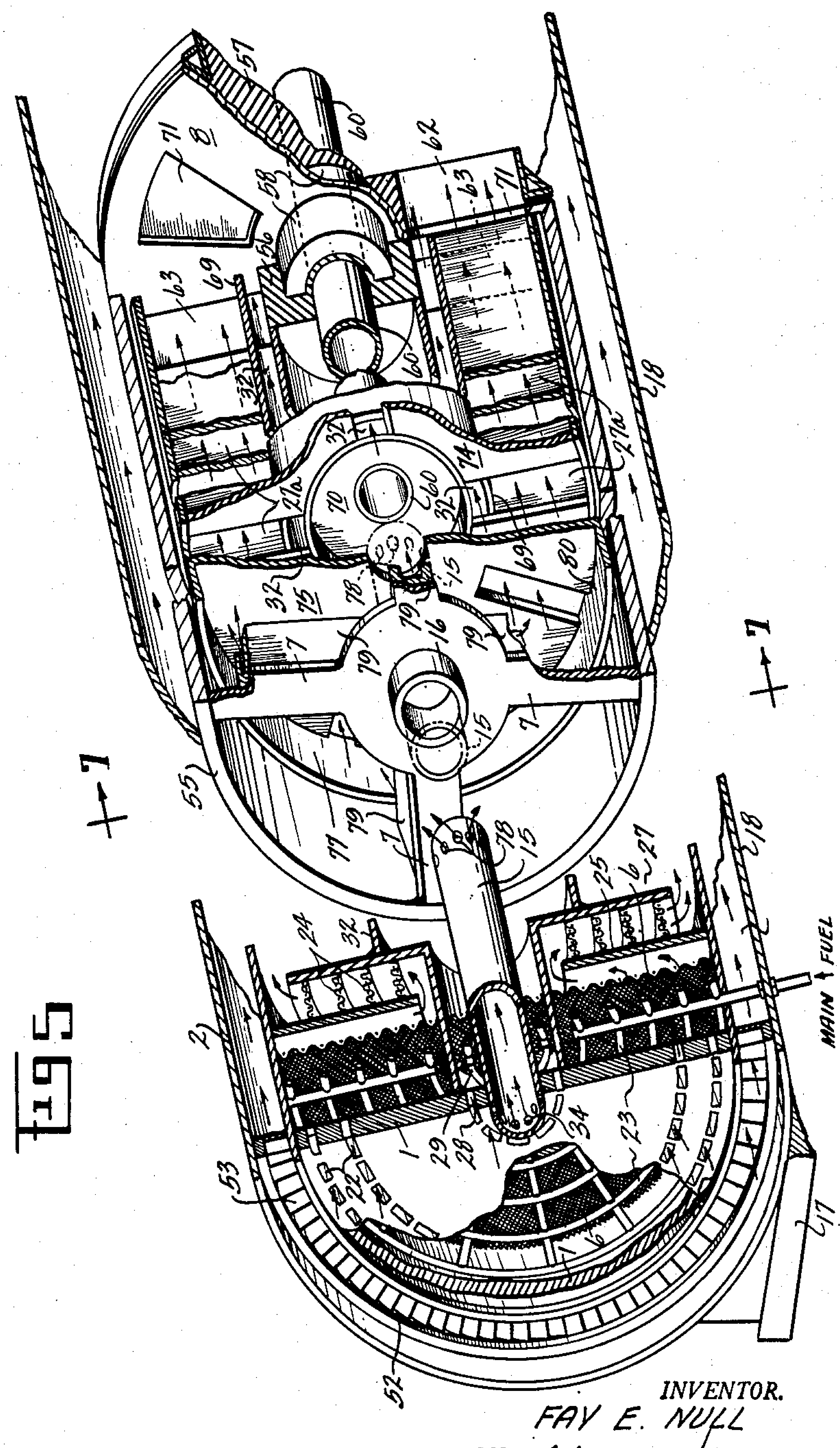


Fig. 5

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AUGMENTED THRUST PULSE JET PUMP OR MOTOR AND METHOD OF CREATING AUGMENTED THRUST OR SUCTION

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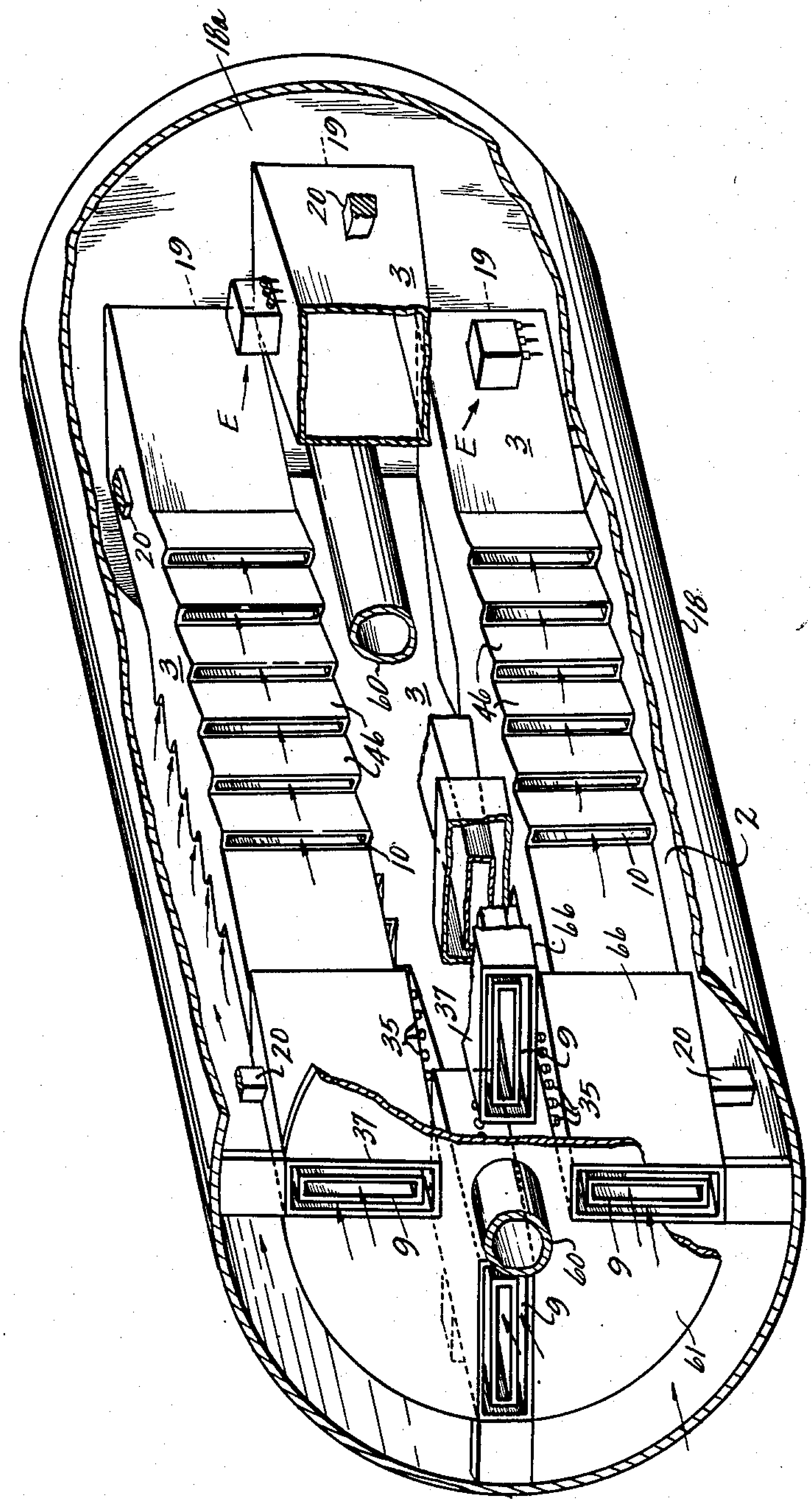


Fig. 6

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Fig. 8

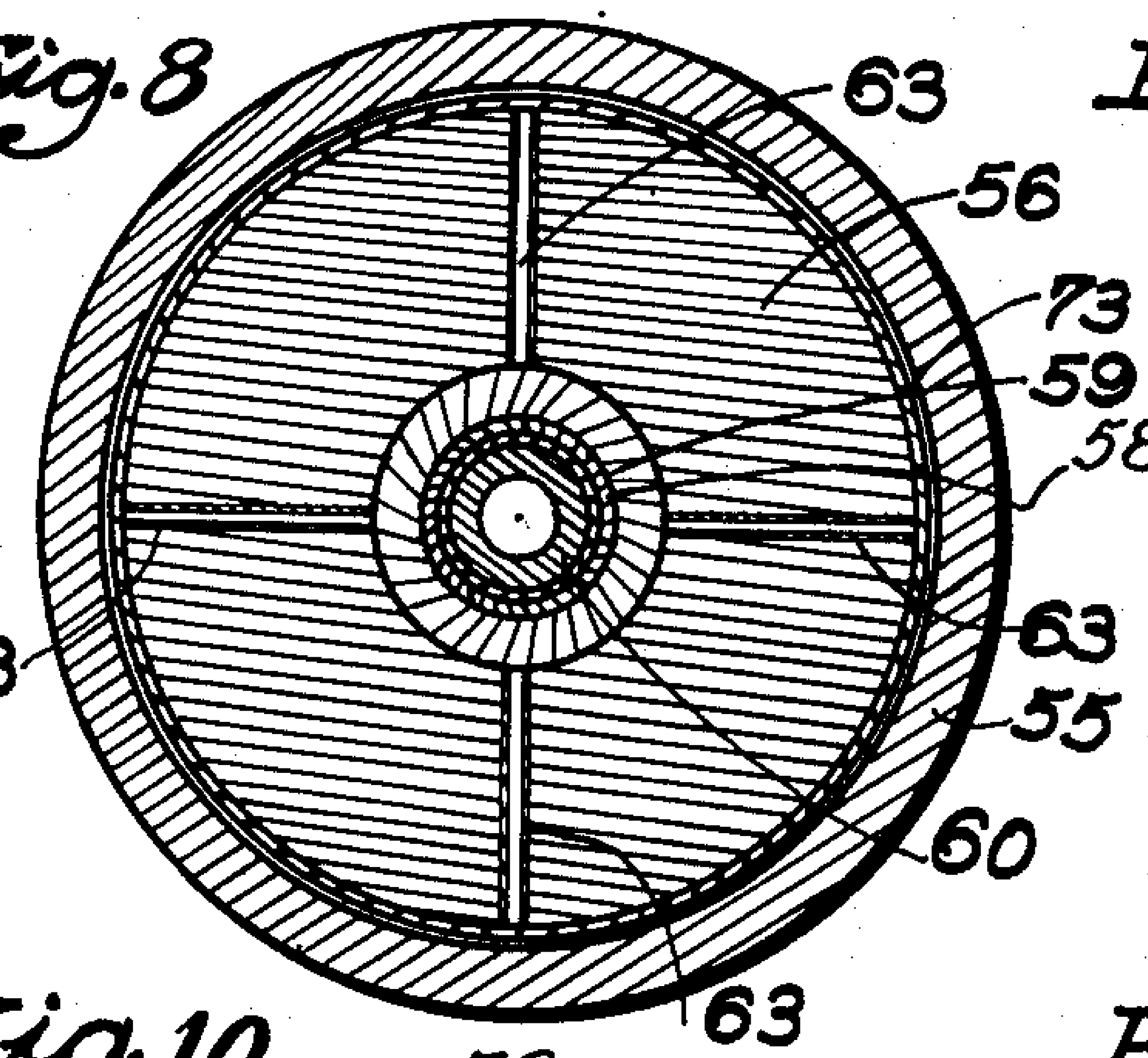



Fig. 9

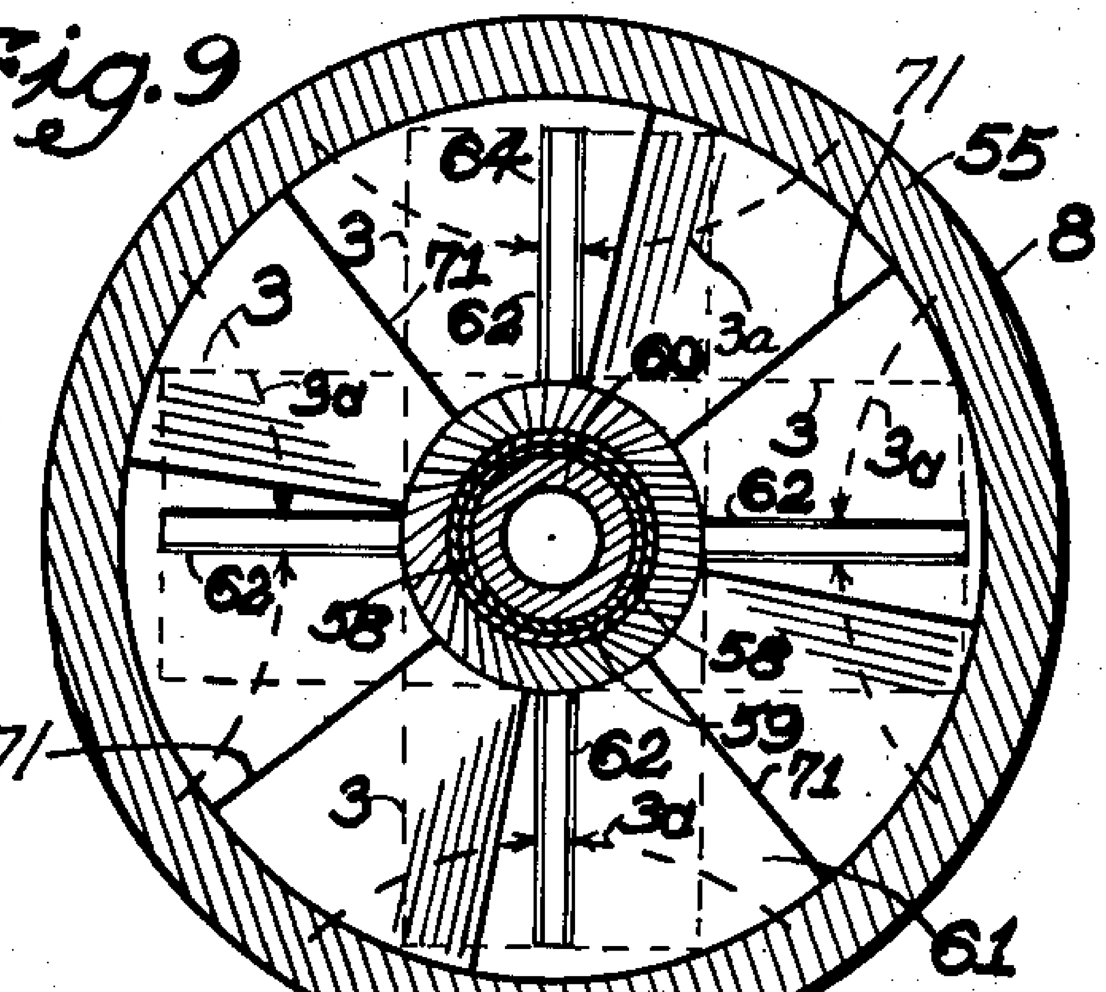



Fig. 10

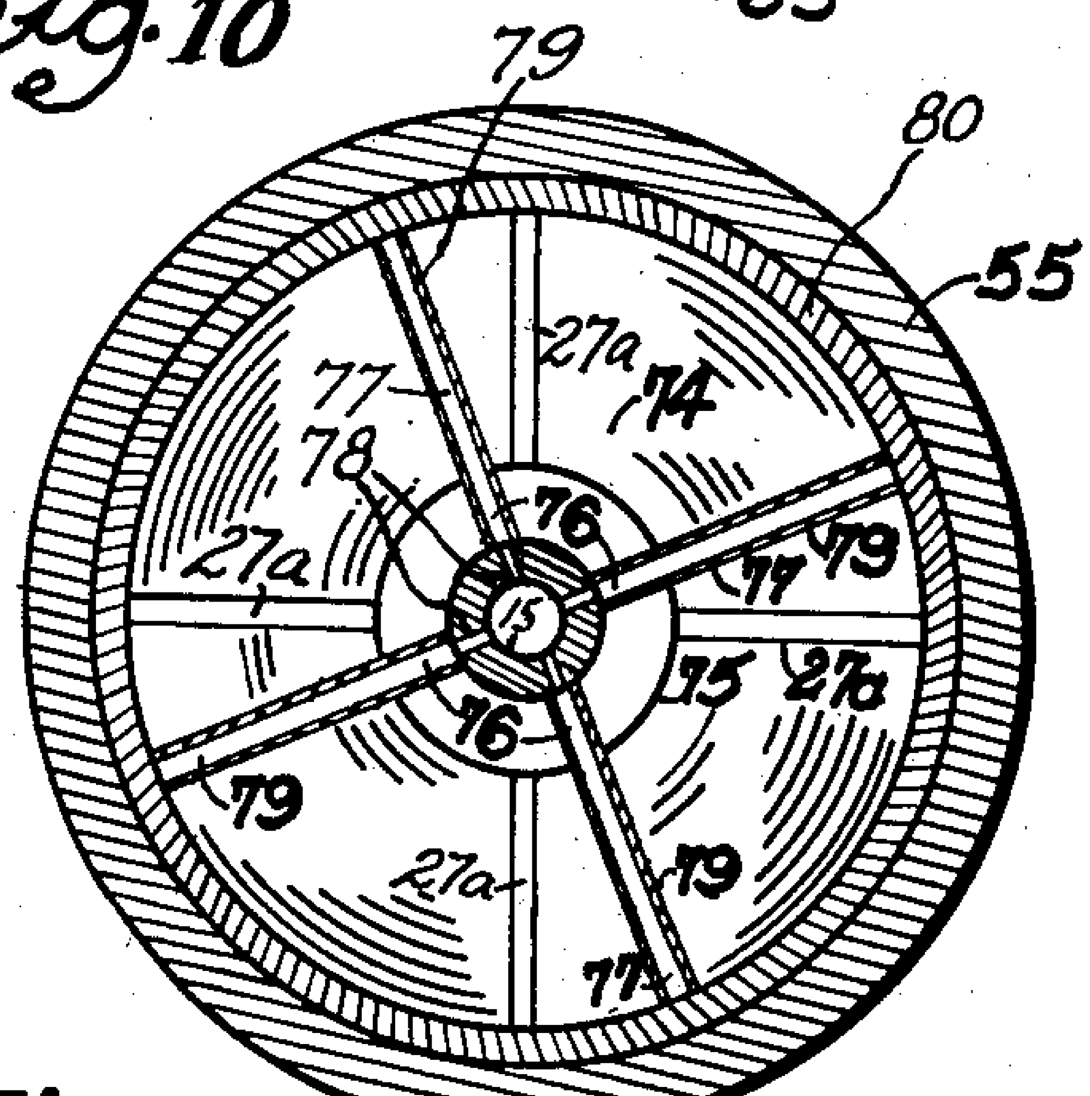



Fig. 11

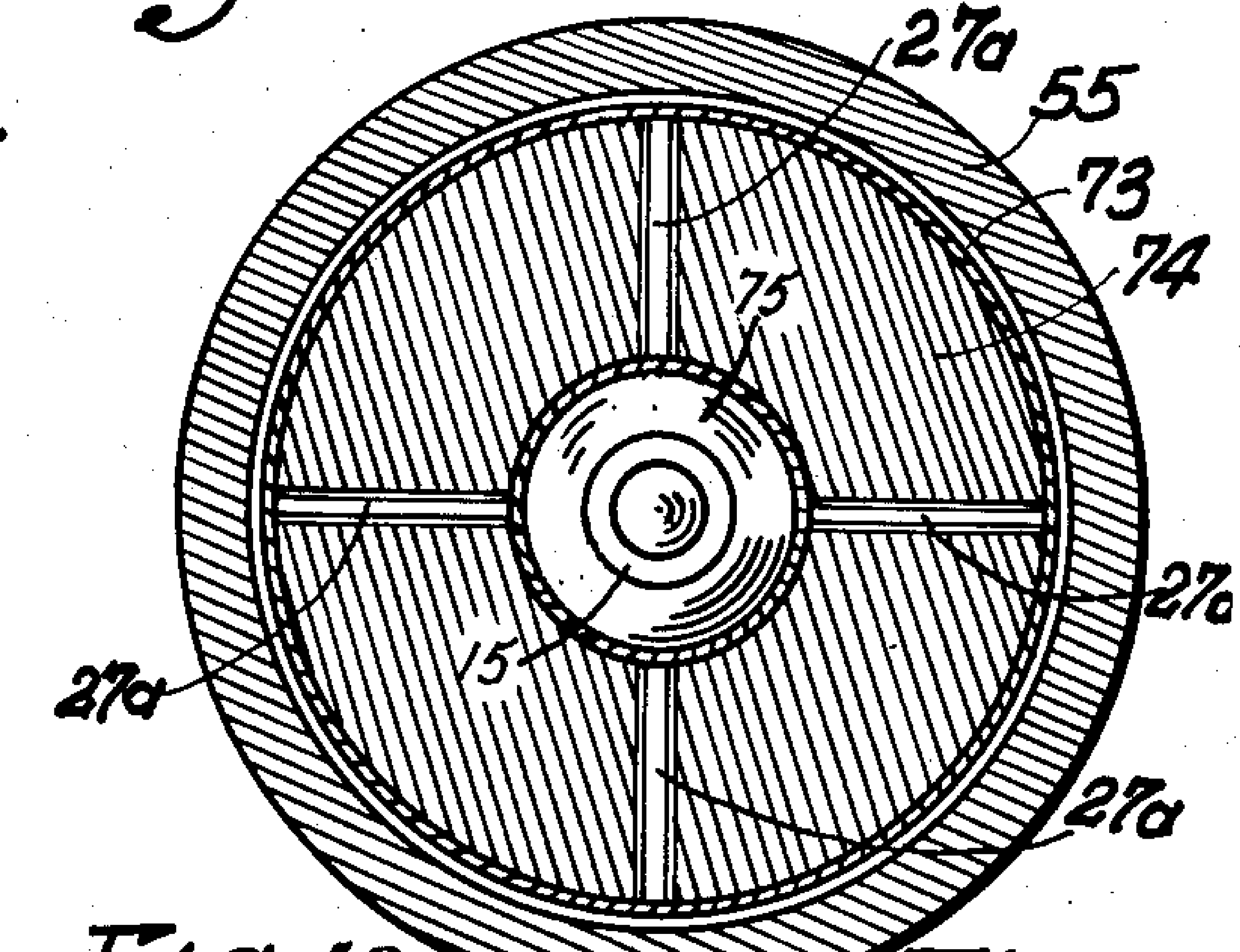



Fig. 12

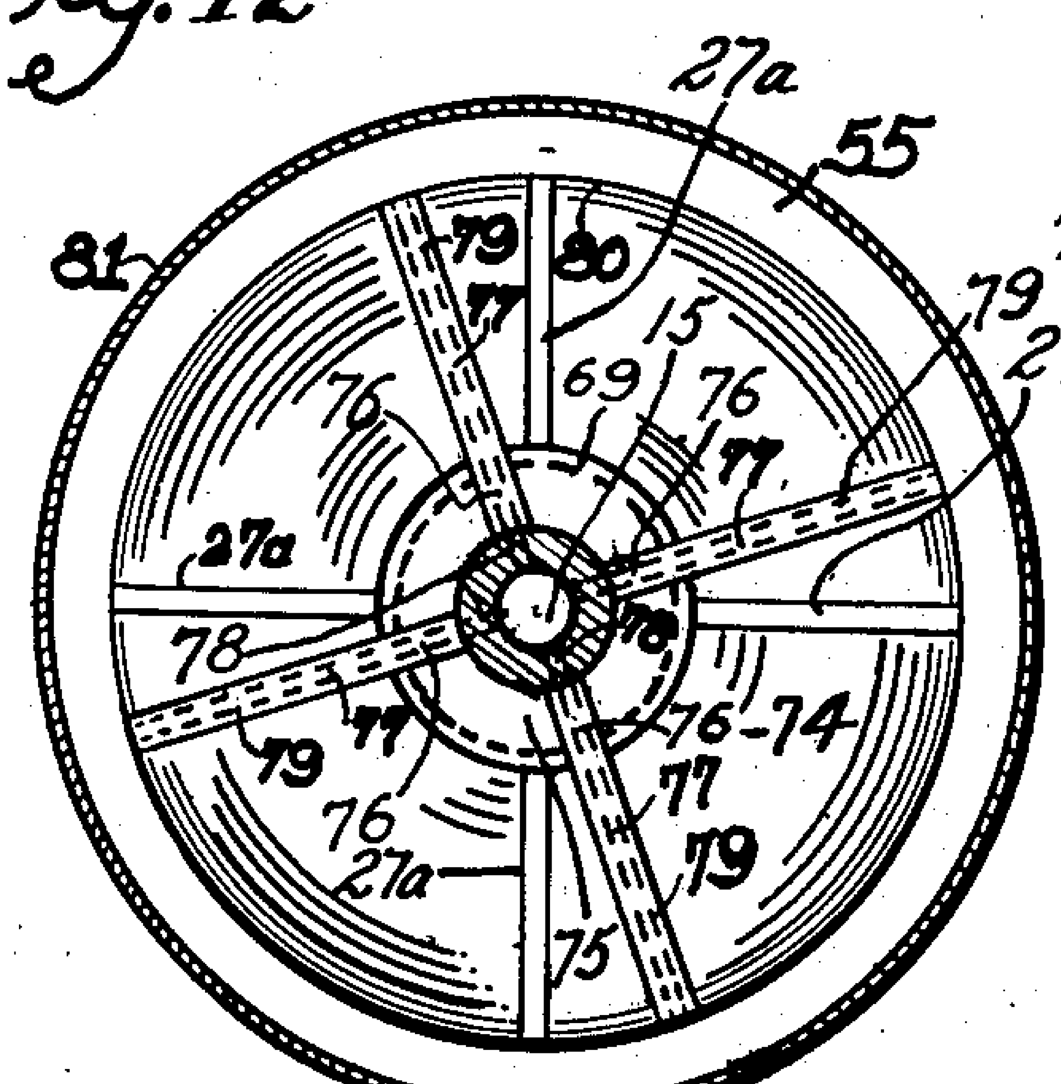
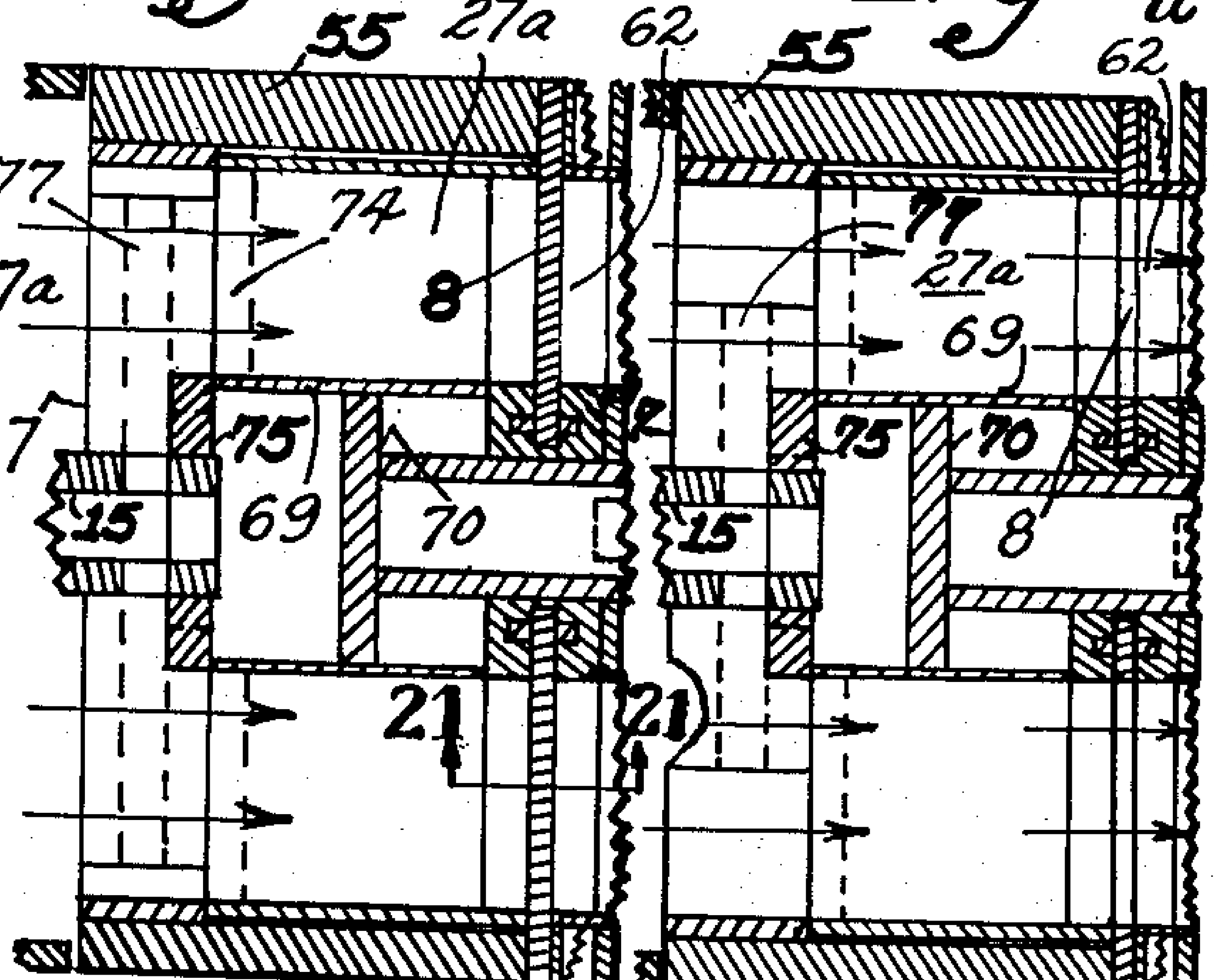



Fig. 13 Fig. 13a

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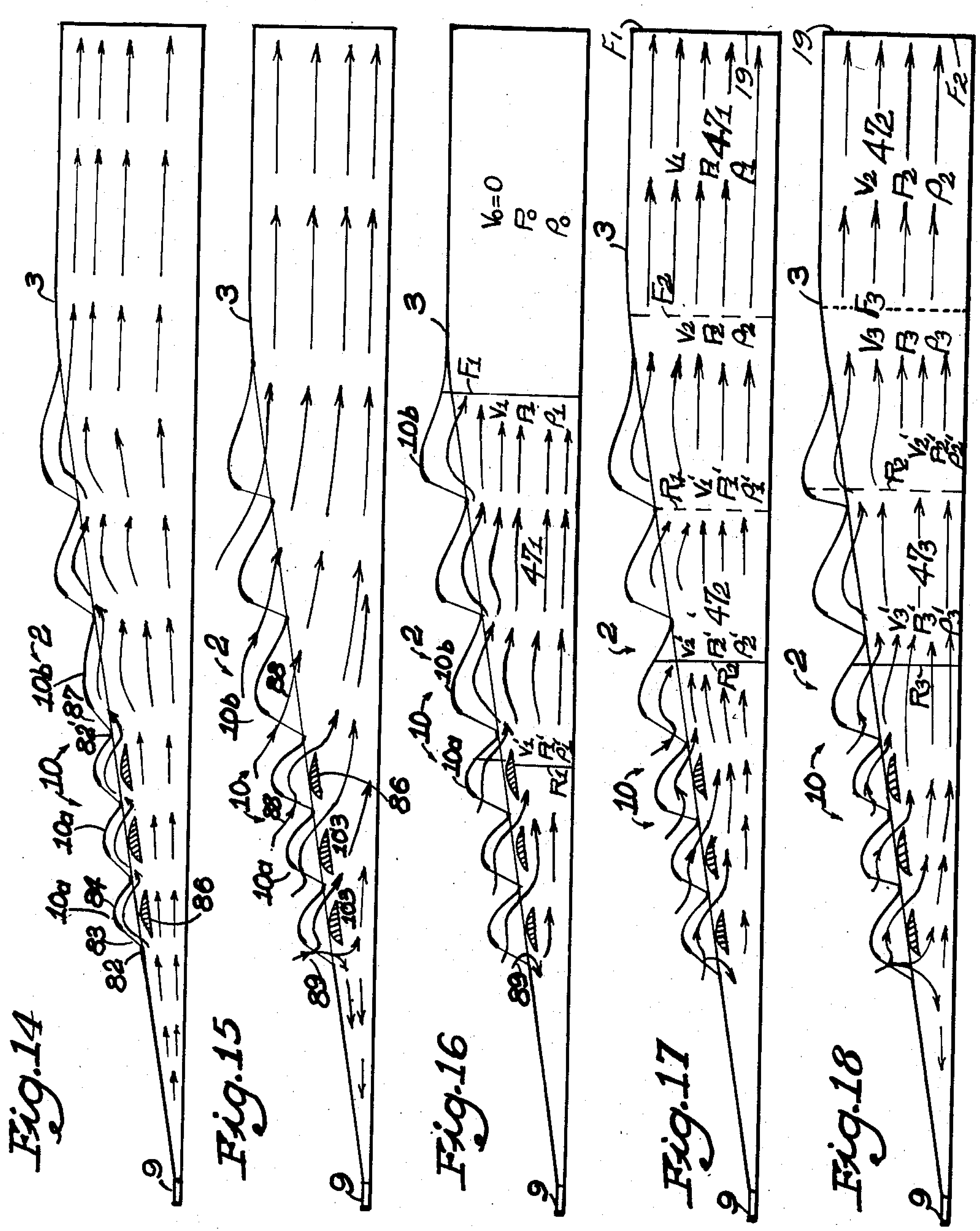


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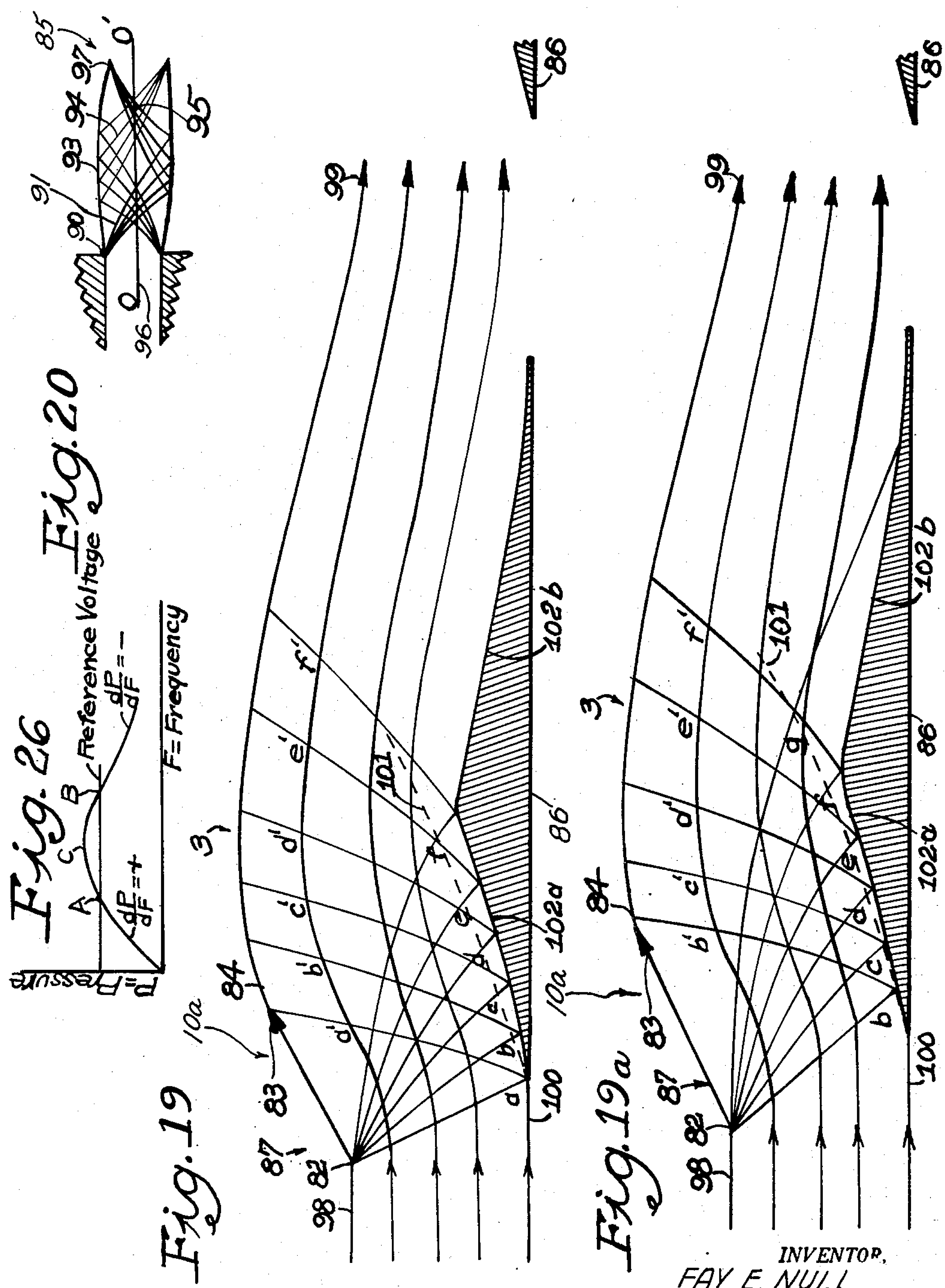


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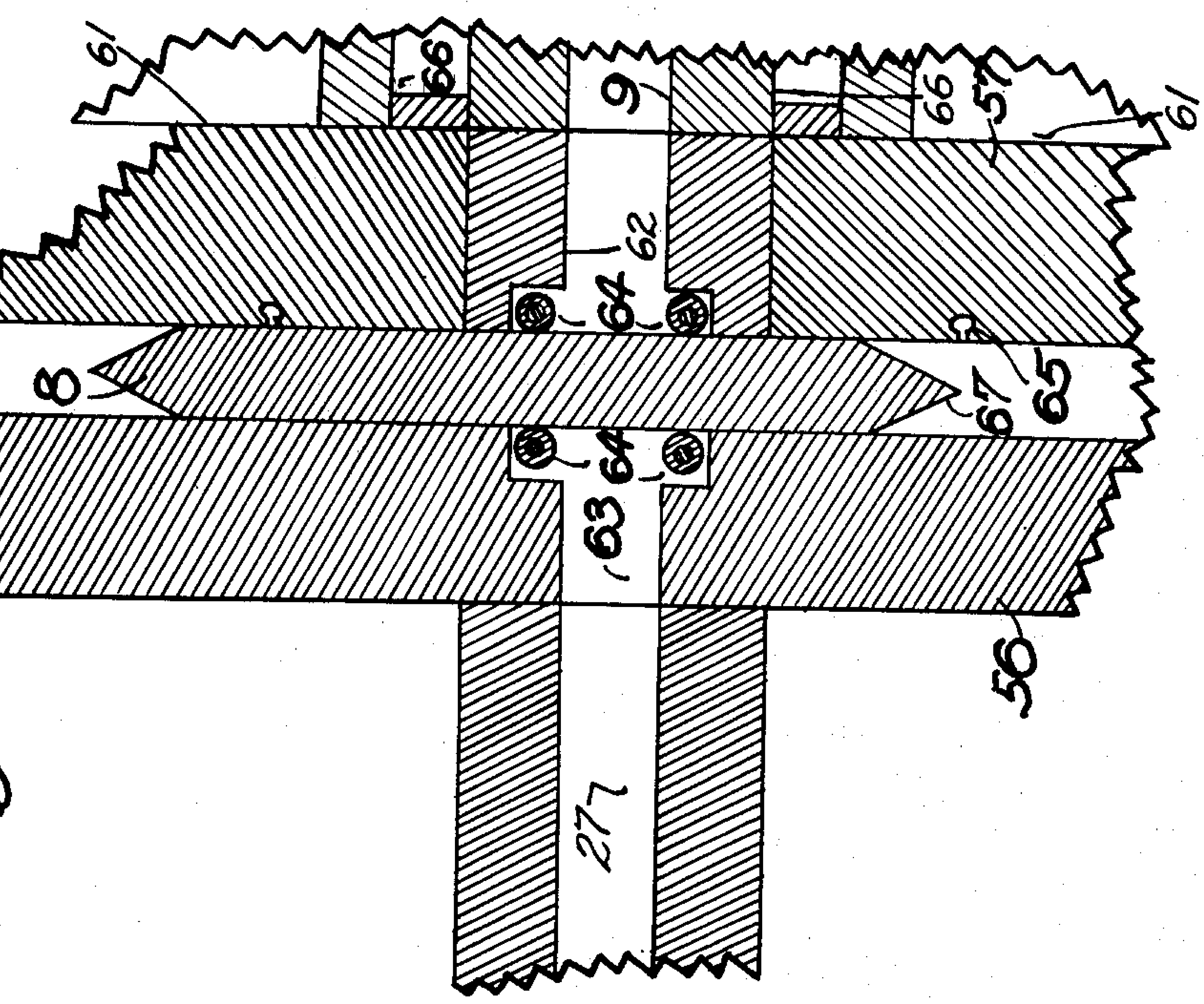


Fig. 21

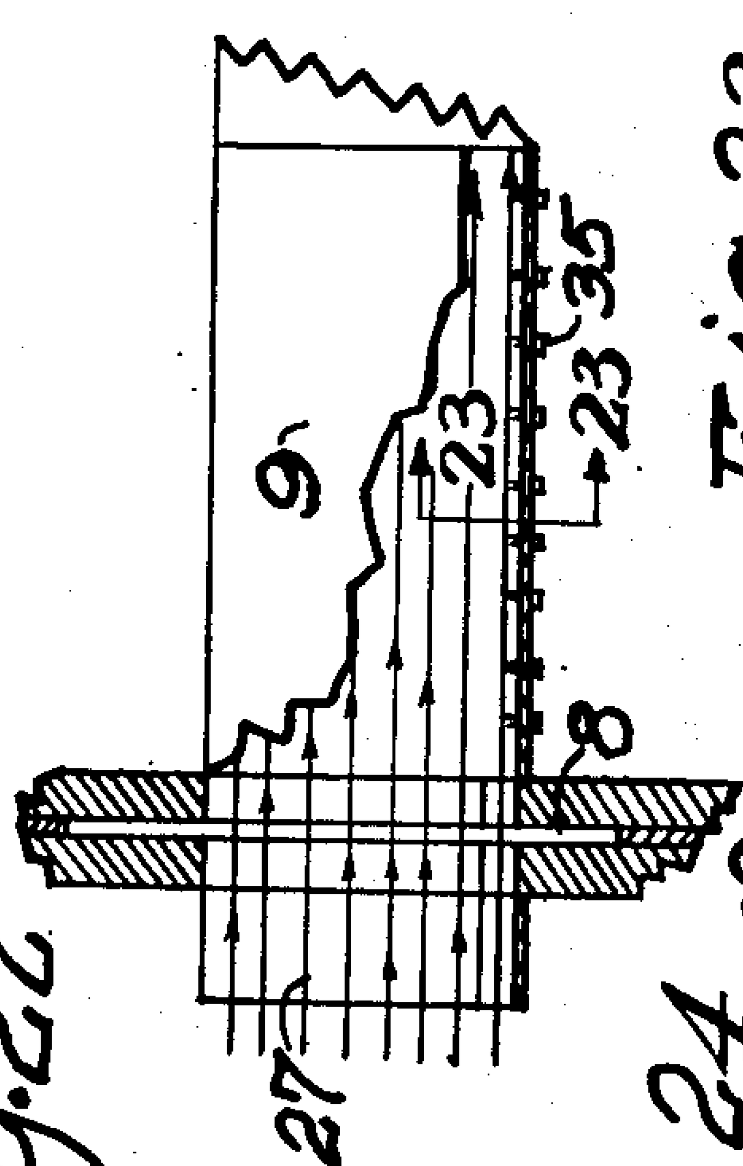


Fig. 22

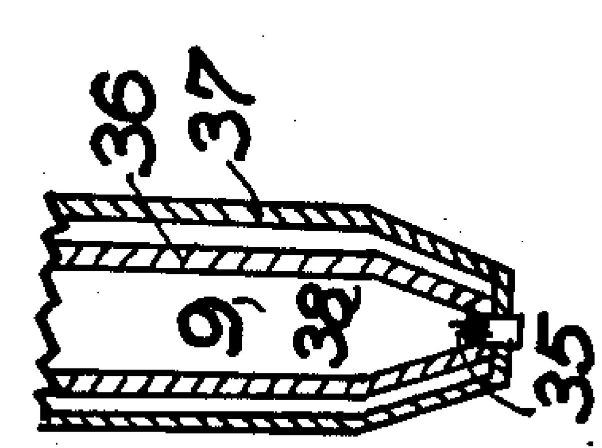


Fig. 23

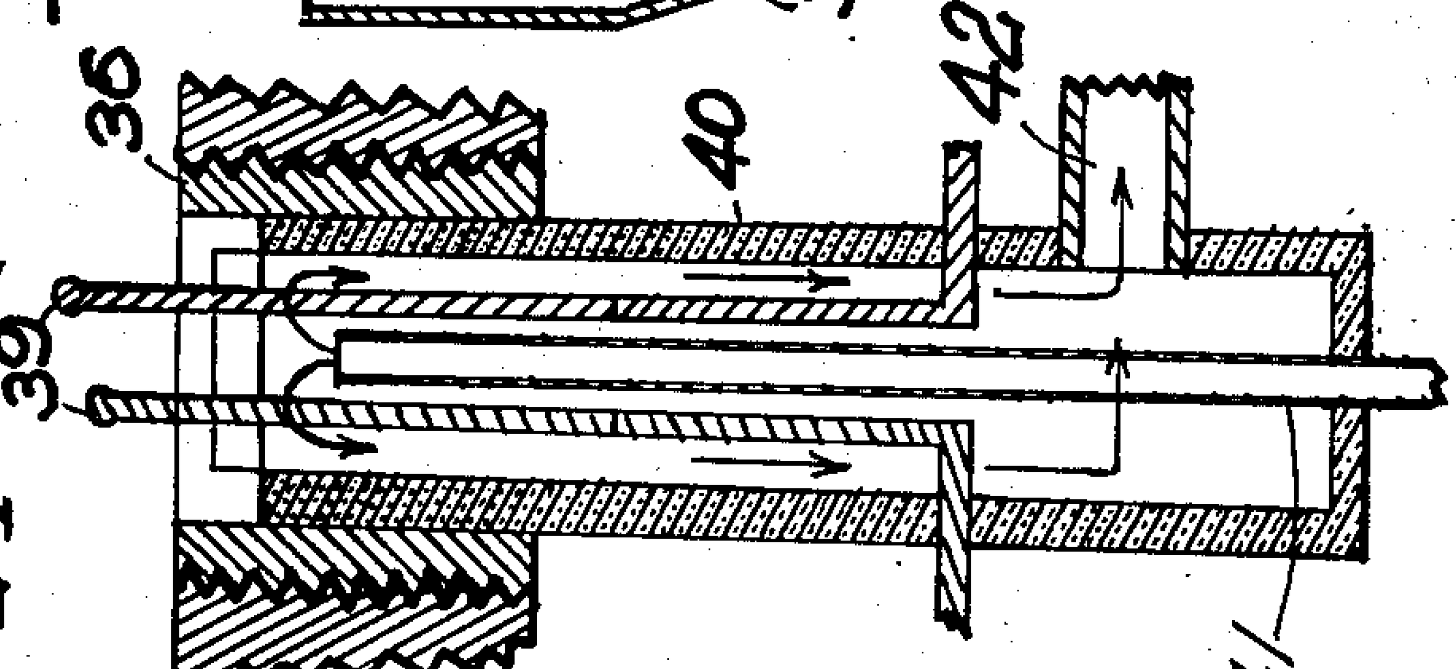


Fig. 24

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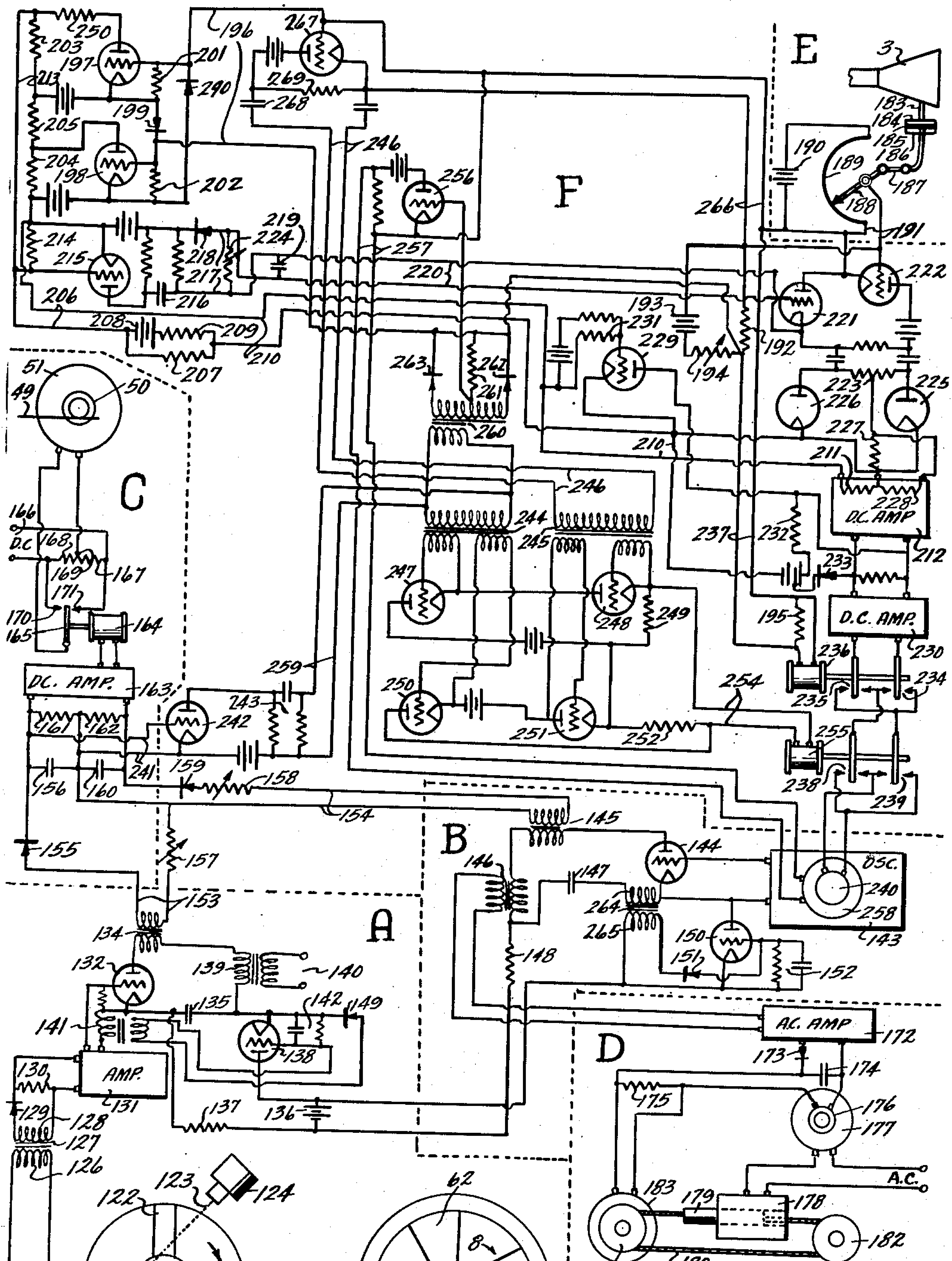


Fig. 25

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Fig 27

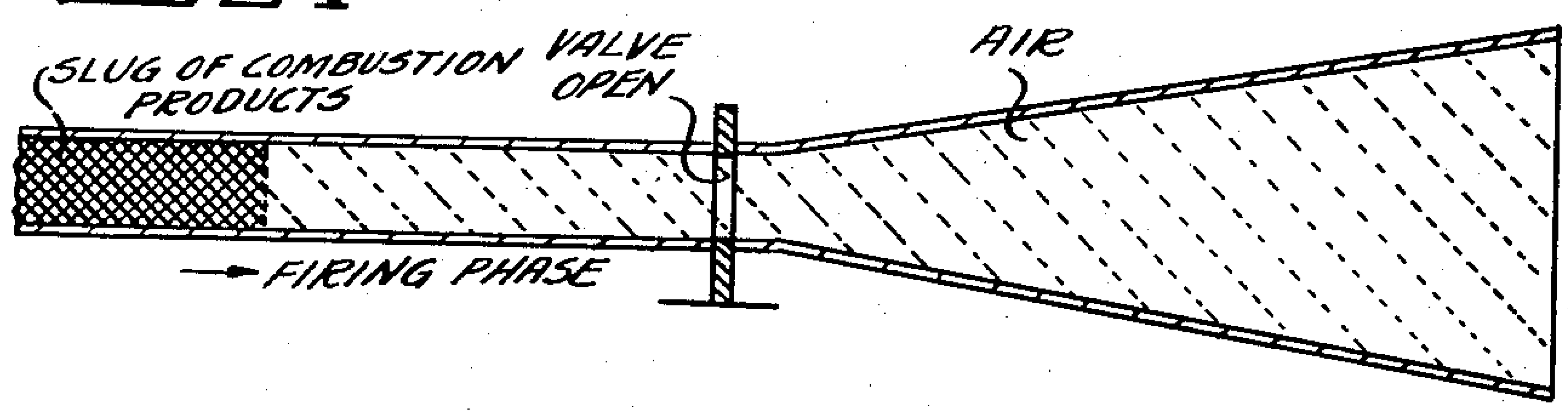


Fig 28

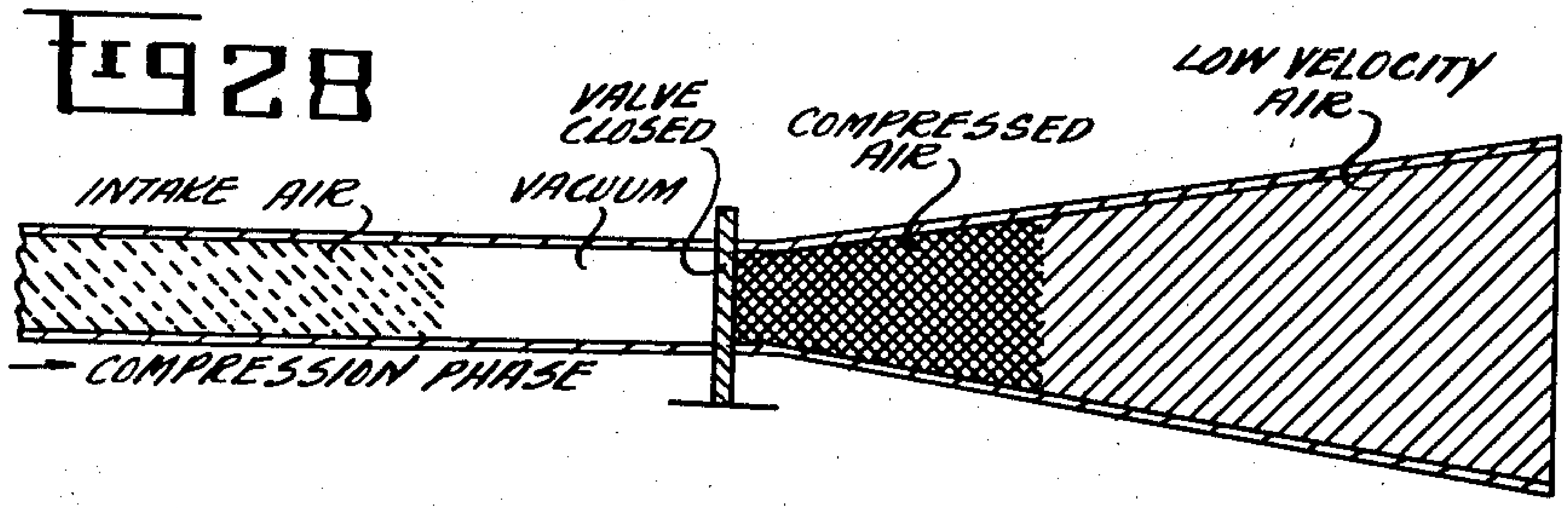


Fig 29

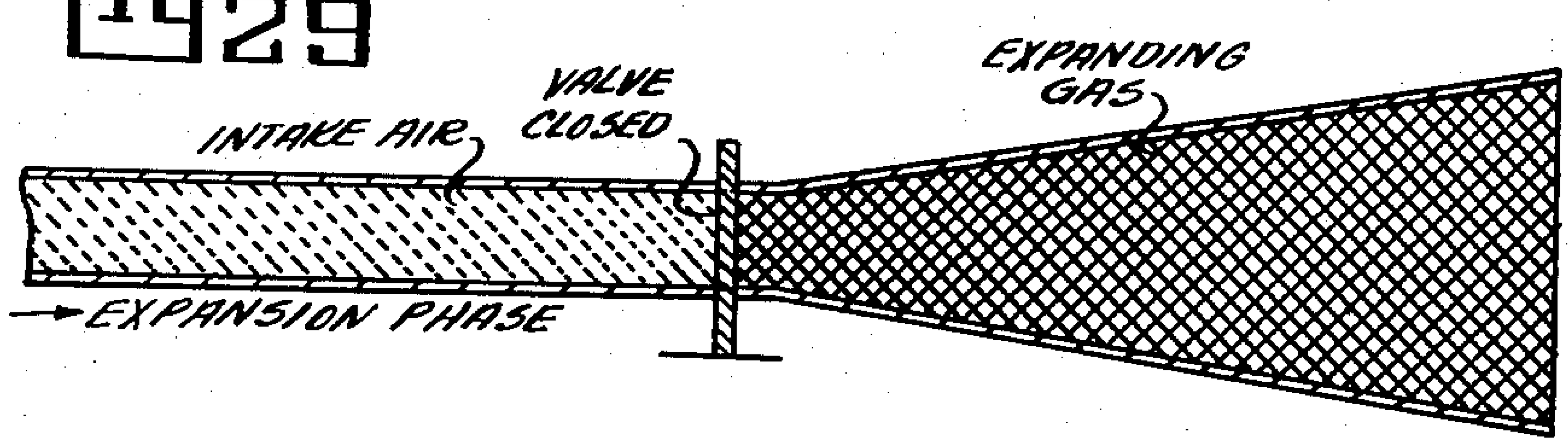


Fig 30

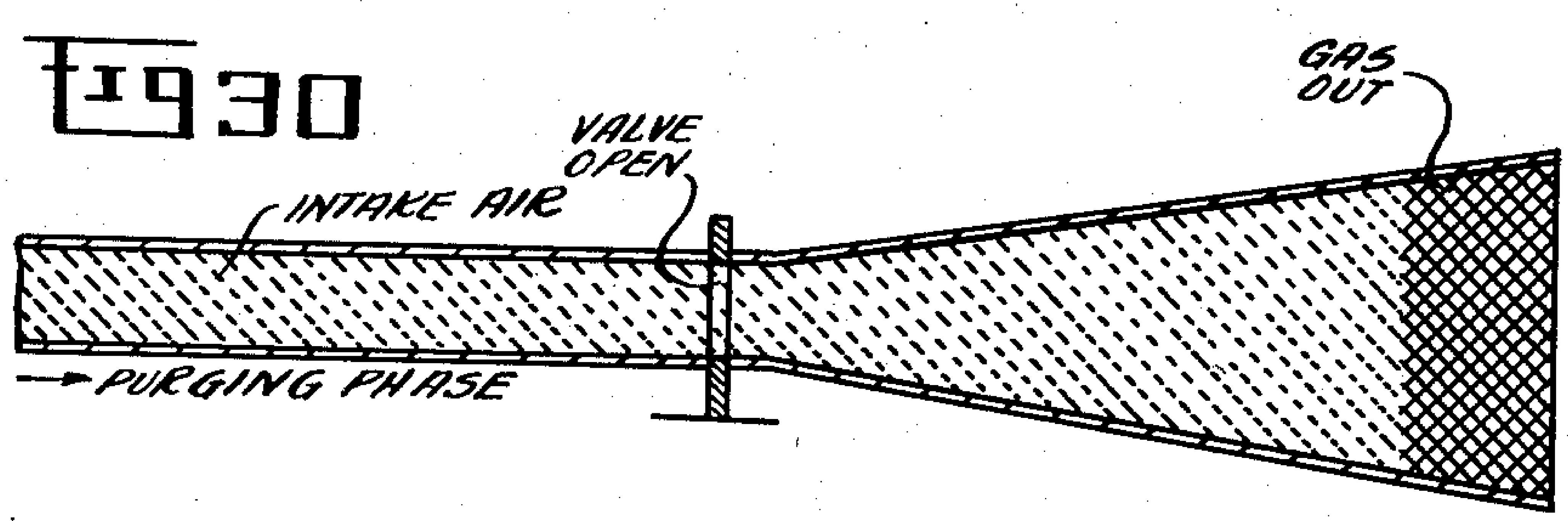


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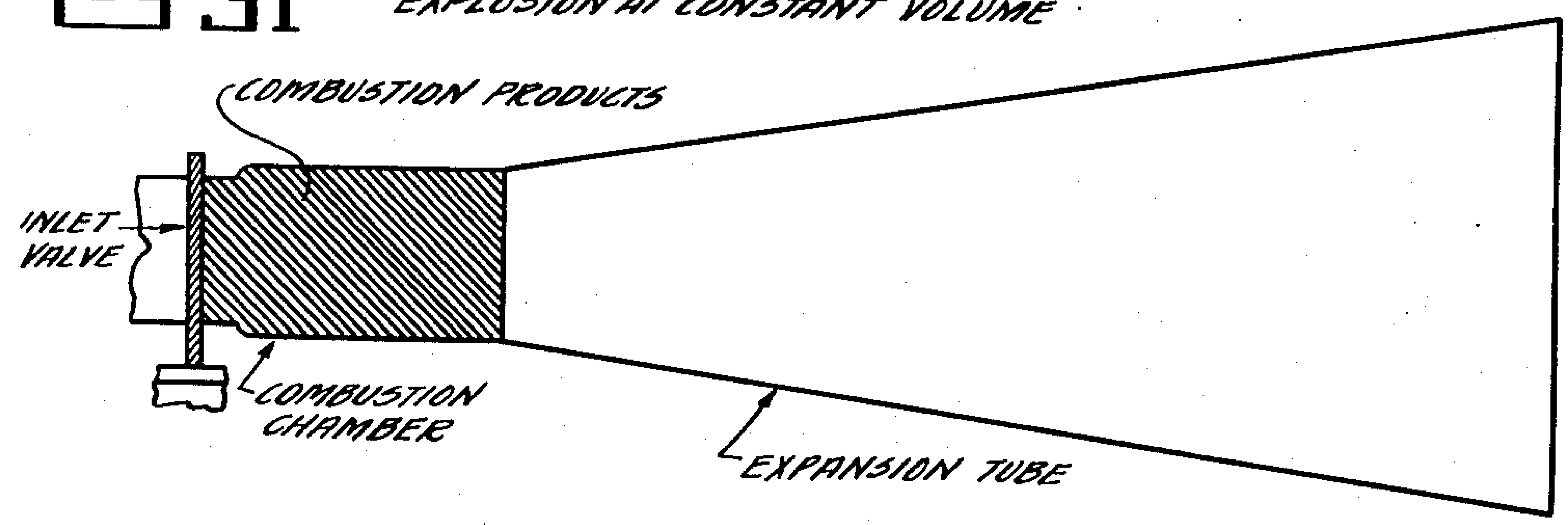
Fig 31



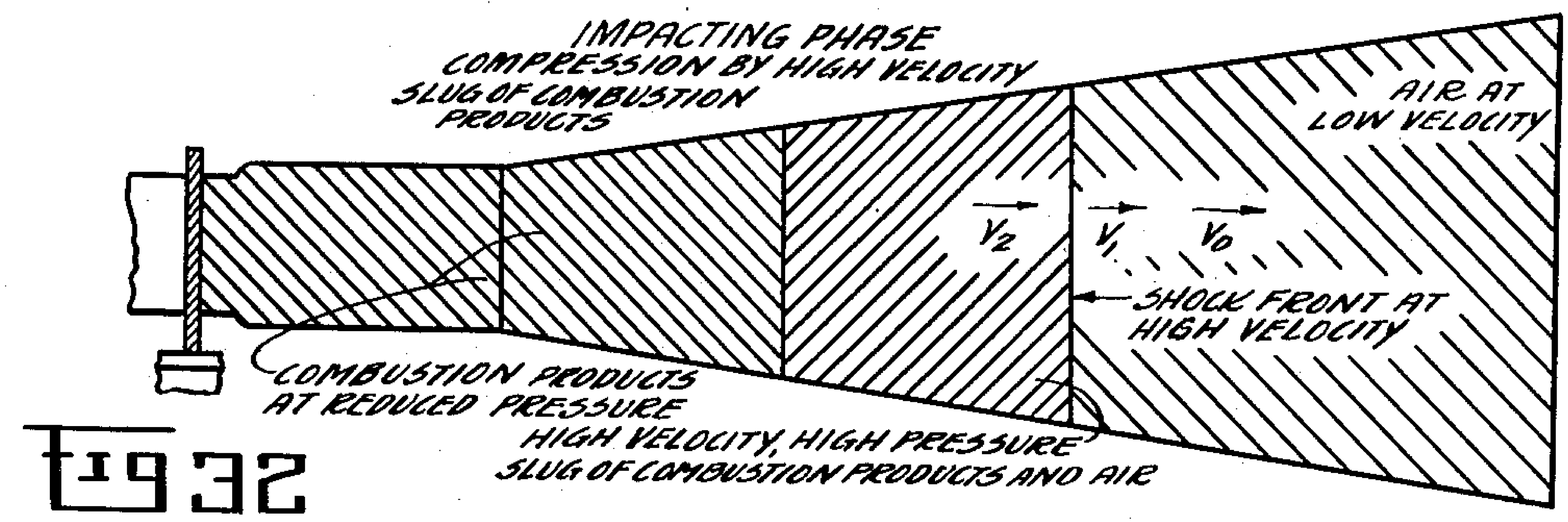




Fig 32

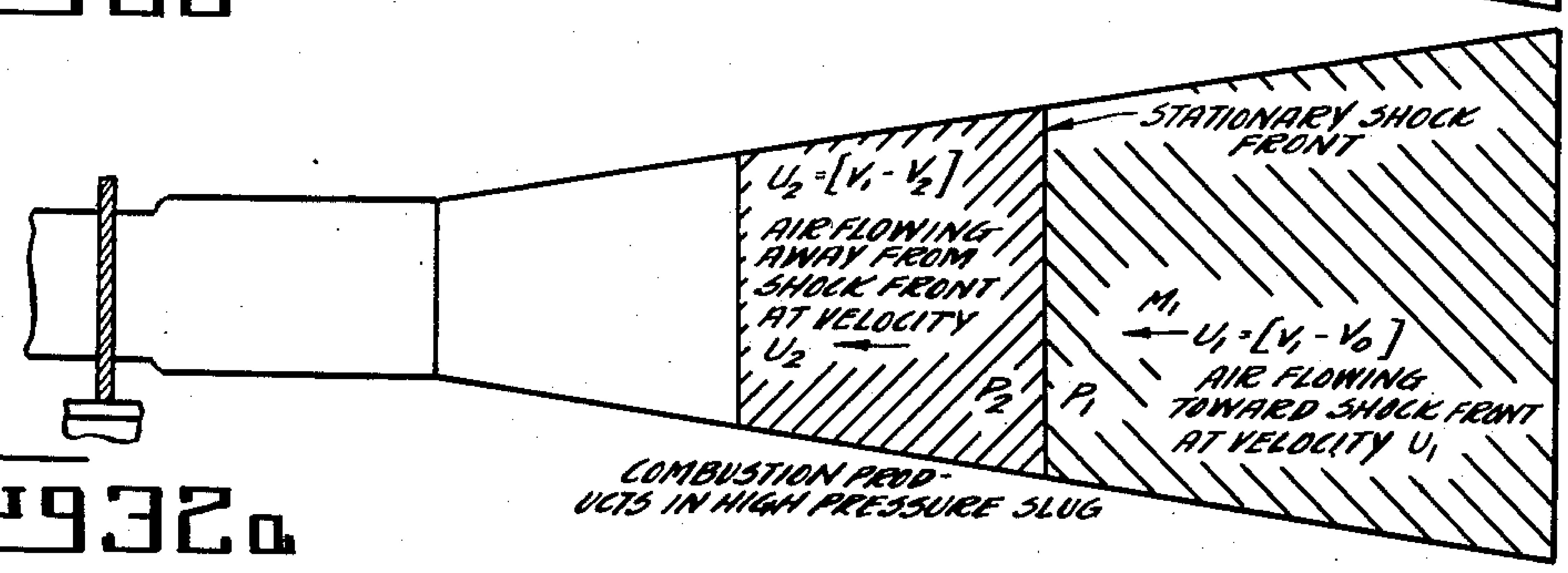



Fig 32a

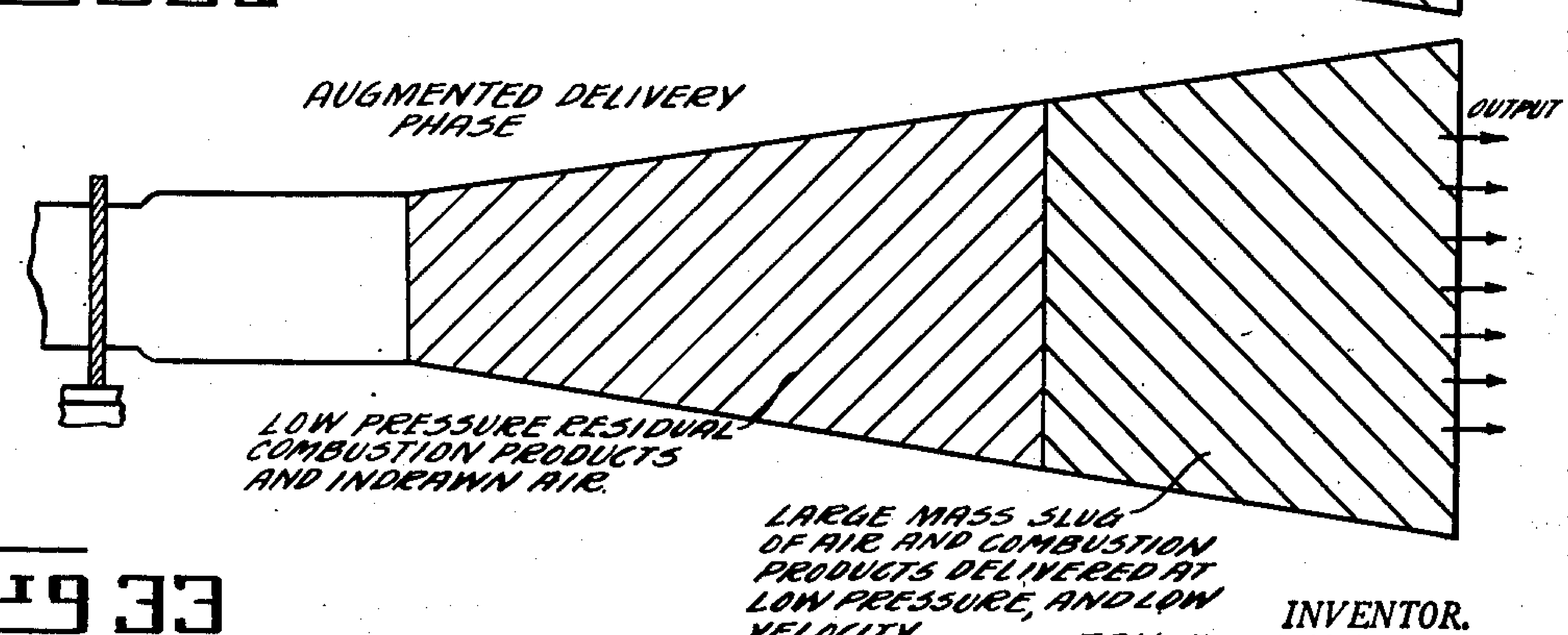



Fig 33

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Patented Nov. 17, 1953

2,659,202

# UNITED STATES PATENT OFFICE

2,659,202

## AUGMENTED THRUST PULSE JET PUMP OR MOTOR AND METHOD OF CREATING AUGMENTED THRUST OR SUCTION

Fay E. Null, Dayton, Ohio

Application June 6, 1950, Serial No. 166,522

32 Claims. (Cl. 60—39.77)

(Granted under Title 35, U. S. Code (1952), sec. 266)

1

The invention described herein may be manufactured and used by or for the Government for governmental purposes without payment to me of any royalty thereon.

This invention relates to an augmented pulse-jet pump or motor of the kind in which a combustible gaseous charge is exploded to form a jet of hot gas and the jet is used to entrain air to build up a substantially continuous current of gas of greatly augmented mass. This current of mixed products of combustion and a large excess of air can be used to change the air in buildings by the process of exhaustion, to produce low vacua, to increase boiler draft, to act as an indirect or direct heating means or to propel aircraft or marine craft.

In my pump or motor, the air from a rotary compressor is premixed with fuel vapors and then enters the firing chamber through a rotary slide disc valve in the presence of an easily detonated vapor near a row of spark plugs. The charge is exploded by a high velocity shock wave from the detonating vapor, and the explosion is so rapid that only a small amount of vapor leaves the open end of the firing chamber during the explosion, which occurs at approximately constant volume. This action causes a maximum pressure and temperature and makes possible a high thermal efficiency. The combustion products expand rapidly in a flared tube to a supersonic velocity; a shock wave with a sharp front edge leading the expanding slug or gas column. As the shock front overtakes the still or low-velocity air in front of it, this air is greatly compressed and added to the slug of combustion products and air. The combined gas and air slug has a high velocity which is determined by the equations of normal shock, the velocity of the air being less than that of the shock front. The pressure on the upstream side of the shock wave must be different from that at the rear of the slug of combined gas and air by the rate of change in momentum of the column. The volume of the slug is determined from the gas equation from the average pressure and temperature of the known mass of the slug. As the slug moves down the tube, its momentum causes the production of a partial vacuum behind the slug which sucks in air through valves along the sides of the flared expansion tube. Therefore the slug is followed by a column of air flowing in at a fairly high subsonic velocity. The lateral filling valves have no moving parts, but consist of vanes and ducts so arranged that the peripheral portions of the slug start a typical Prandtl-Meyer expansion around the corner of the valve opening between the expansion tube and low pressure chamber. A special guard vane is employed to separate the peripheral flow from the main flow in the expansion tube. The upper surface of this guard vane is shaped to reflect the expansion waves incident upon it from the corner of the valve opening to an outer vane the tip of which is approximately tangential to the stream of expanding gas and which is curved to lead back to the expansion tube proper. The formation of oblique shock waves along this outer vane is prevented by the incidence of the reflected expansion waves, which cancel out the oblique shock waves which would otherwise form along this surface. When the peripheral portions of the gaseous slug reach the valve opening to the low pressure chamber, they flow in a typical Prandtl-Meyer expansion around a corner until they reach the reflected expansion waves which deflect the flow back toward the expansion tube. The flow pattern is somewhat different for the front and rear portions of the slug, which travel with different velocity. However, a smooth flow results in each case, with the formation of only weak shock waves and with a small turbulence loss. When the low pressure tail of the gaseous slug reaches the lateral valve openings, air from a low pressure chamber flows in to fill the expansion tube. The low pressure chamber surrounds the expansion tubes and has a turbine at the front air entrance. As the air from the chamber rushes into the expansion tubes, the pressure in the chamber is decreased. Air entering the chamber drives the turbine which is geared to an air compressor which supplies high pressure air to the firing chambers for combustion of the fuel. Before one slug of combustible gas and air reaches the end of an expansion tube, a succeeding slug has been fired and its front has collided with the rear end of the preceding slug, thereby compressing it, and causing the output pressure and the velocity from the expansion tube to be fairly constant. Small pressure variations are present, however, and have the same frequency as the slugs fired in a given tube, i. e., several hundred per second in an expansion tube 15 feet long. The flow of air into the low pressure turbine chamber may be used as an exceedingly fast large volume suction pump for exhausting air and fumes from buildings or for commercial processes requiring a vacuum which need not be constant. The exhaust streams from the ends of the expansion tubes may be used as an exceedingly fast, large volume ejector pumping means for forced draft on boilers and commercial processes where a small percentage of combustion products in air is of small importance, or for indirect heating systems. Because of the initial high pressure and temperature of the combustion products the thermal efficiency is quite high, and such an augmented jet of gases furnishes an efficient means of aircraft propulsion for speeds up to 300 to 400 miles per hour. Because of the non-turbulent augmentation of momentum which is possible with a pulse jet engine, a small mass of very high velocity gas produced with high thermal efficiency is changed by my device with high mechanical efficiency into a very much larger mass of low velocity, relatively low pressure gas. The ratio of the thrust produced by the large gaseous mass M, which is a low velocity exhaust jet, over that produced by the original high pressure, high velocity, small gaseous mass $m$ without augmentation, is $\sqrt{M/m}$. It has been found impractical to produce efficient augmentation of the momentum of a jet by adding air to a steady flow of gas flowing at appreciably different velocities without excessive turbulence along the boundary line. The normal shock wave produced in an expansion tube by the expanding gas slug impacting on the slower moving air in front of it, reduces the momentum gain ratio to about 87% of the theoretical no-shock-loss value, when the exit velocities have been reduced to several hundred feet per second. The momentum augmentation of the pulse jet is therefore, however much higher than for a jet with steady flow. The cost of fuel for the above pump is decidedly less than the cost of electricity for a motor-compressor unit of the same capacity. In addition the volume, weight, and original cost are very much less for the pulse jet pump or motor described above. In the case of an indirect heating system with forced draft, the efficiency is still higher, as the mechanical energy loss due to the shock wave in the expansion tubes is converted into usable heat. Such additions or modifications may be made without departing from the spirit of this invention.

It is therefore among the objects of the present invention to provide a very high capacity valve controlled pulse jet pump or motor that may be used for vacuum, pressure, vacuum and pressure simultaneously, or for propulsion, and which has the advantages of small weight, less floor space, lower initial cost, and lower operating costs than the conventional electric motor and centrifugal or axial flow compressor units.

More specifically, one object of the invention is to obtain high thermal efficiency by an explosion occurring at constant volume in a firing chamber, the exhaust end of which is open and which leads to an expansion tube, by the action of a detonating shock wave from a detonatable mixture admitted to the edge of the firing chamber near spark plugs or other ignition means.

Another object of the invention is to provide a pulse jet pump or motor having a rotary disc valve which gives positive control to the admission of a premixed air and fuel vapor mixture to the firing chambers.

Another object of the invention is to provide a pulse jet pump or motor having air inlet valves to the expansion tubes having no moving parts, such valves being adapted to prevent the escape of high pressure, high velocity gas or air from the sides of the expansion tubes as the compressed piston or slug of gas and air from a given explosion pulse travels toward the mouth of the expansion tube. Such valves, however, allow air to enter the expansion tubes by the action of the partial vacuum produced in the wake of the slug of gas and air as it travels through the expansion tube.



Another object of the invention is to provide in a jet pump or motor, means to transform the small mass, high velocity jet from the firing chamber into the low velocity, but much larger mass jet produced at the exits of the expansion tubes by the passage of the normal shock wave front which leads the initial slug of high velocity gas discharged from the firing chamber and which compresses the lower velocity air in its path, this compressed air adding to the mass and volume of the high velocity slug of gas so that the gaseous slug grows in mass as it passes along the expansion tube.

Another object of the invention is to provide in a jet pump or motor, a low pressure chamber partially evacuable by valves leading to expansion tubes, and having a turbine driven by the air which enters the low pressure chamber. This turbine is adapted to drive a compressor to compress combustion air which is then premixed with the fuel vapors and admitted to the firing chambers through rotary valves.

Another object of the invention is to provide in a pulse jet pump or motor, an adjustable firing-frequency means so that before a slug of compressed air and gas from one shot clears the expansion tube, it is impacted from the rear by the head of the slug of compressed air and gas from a succeeding shot, the high pressure head of the succeeding slug compressing the low pressure tail of the preceding slug, and providing a more uniform pressure and velocity of the exhaust from the expansion tubes.

Object and advantages other than those above set forth will be apparent to those skilled in the art from the following description when read in connection with the accompanying drawings, in which:

Fig. 1 is a front elevation taken from the inlet end;

Fig. 2 is a side elevation, the internal parts being shown in dashed lines;

Fig. 3 is an elevation of the invention taken from the outlet end;

Fig. 4 is a sectional view in side elevation of the pump or motor with the case cut away from the rear portion, and the case cut away from the front portion to show a vertical section through line 4—4 in Fig. 1;

Figs. 5 and 6 are perspective longitudinally broken-open views of my new pump or motor taken outward from the line 5—5 of Fig. 4; views 5 and 6 are to be taken together, Fig. 6 forming a continuation of Fig. 5. The latter is shown partly exploded at the compressed air feeding means to show in phantom how the hollow axle fits into the rotary air feed and the holes through which air enters and leaves the axle. Fig. 6 shows the central supporting tube broken away, also one of the expansion tubes exploded to show its internal construction;

Fig. 7 is the enlarged portion of the horizontal section through the central axle indicated by the line 7—7 of Figs. 2 and 5 in the vicinity of the valve to the firing chambers;

Figs. 8, 9, 10, 11 and 12 are vertical sections of the valve region shown in Fig. 7, the sections being taken on lines 8—8 to 12—12, respectively;

Figs. 13 and 13$a$ show horizontal sections for two positions of the valve shown in Fig. 7;

Figs. 14 and 15 are schematic diagrams of successive flow patterns in an expansion tube. Fig. 14 shows the action of the inlet valves when the pressure in the expansion tube is greater than that in the surrounding chamber. Fig. 15 shows the action of the inlet valves when the pressure in the expansion tubes is lowered in the wake of a slug of gas and air passing down a tube;

Figs. 16, 17 and 18 show the positions of compressed air slugs in the expansion tube in different phases of the firing cycle. Fig. 16 shows the initial slug of compressed air, Fig. 17, the overtaking of the first slug by the second, and Fig. 18 the overtaking of the $n$th slug by the $n+1$ slug after steady conditions have been reached;

Fig. 19 is an enlarged schematic view of an inlet valve with typical expansion wave reflections for the rear of a slug traveling at relatively low supersonic velocity. Fig. 19*a* shows the same valve as in Fig. 19 but for the relatively high supersonic velocity of the front of the slug of compressed air and gas;

Fig. 20 shows the vertical section of a supersonic jet expanding from an orifice into a region of lower pressure;

Fig. 21 is a portion of an enlarged vertical section along line **21—21** in Fig. 13 and extending across the edge of a horizontal firing chamber;

Fig. 22 shows an elevation of the bottom firing chamber of Fig. 4 with a portion of one wall removed to show the spark plugs in the lower portion, with a vertical section of the adjoining valve wall;

Fig. 23 is a vertical section along the line **23—23** in Fig. 22;

Fig. 24 is an enlarged detail of the vertical section of a spark plug in Fig. 22;

Fig. 25 is a schematic wiring diagram of the automatic controls for the present invention;

Fig. 26 shows a graph of operational characteristics;

The above figures illustrate a special apparatus embodiment of the present fundamental invention. The following Figs. 27 through 30 illustrate another special embodiment of the fundamental process.

Figs. 27 to 30 inclusive are diagrammatic representations of a flaring tube provided with a valve at the beginning of the flare. Successive cyclic phases are indicated, the various conditions and kinds of gases in the tube being shown by different kinds of hatching, legends being provided for the purpose of identifying the gases. The invention illustrated by these figures is a special method of operating an augmented pulse jet engine, as distinguished from the fundamental general method illustrated in the remaining figures as follows:

Figs. 31 through 33 illustrate different phases of the fundamental process. Fig. 31 shows the Explosion Phase, Figs. 32 and 32*a* the Impacting (Augmentation) Phase, and Fig. 33 is the Augmented Delivery Phase.

Referring more particularly to Fig. 1, the blades of turbine **1** are driven by air flowing into the low pressure chamber **2** (Figs. 2 and 3) which surrounds the expansion tubes **3**. **4** is the inlet to the compressor **5** from which compressed air passes through vane slit openings **22** in the disc of the turbine **1** (Fig. 4) to the air-fuel premixing chamber **6**, air-cushion feed **7**, rotary disc valve **8**, firing chambers **9**, and expansion tubes **3**. After the firing chambers **9** have been filled with a premixed charge of air and fuel and an air cushion next to the valve, the valve closes, the charge is fired, and a slug or piston **47** (Fig. 16), of high pressure, high velocity gas and air expands down the expansion tubes **3**. Due to the momentum of this high velocity slug, a low pressure area follows in its wake and air from low pressure chamber **2** rushes into the expansion tubes **3** through valves **10**. This lowers the pressure in chamber **2** and external air rushes in through duct opening **11** (Figs. 2 and 4), part of the flow being bypassed around the turbine **1** by variable length cylindrical vane **12**. The velocity of the air going through the turbine determines its speed and thereby largely the speed of the entire motor. The turbine **1** drives the air compressor **5** through a conventional gear box in the container **13** which also contains a conventional starter motor (not shown) and electronic control equipment which will be explained later in connection with Fig. 25. The container **13** is carried by a support **14**, which also mounts the front end of the main axle **15**, the other end of the axle **15** being carried by a support **16**. The supports **15** and **16** are mounted on a base **17** which also supports an outer shell **18** which forms the outside surface of the low pressure chamber **2** and has a semi-rounded rear end **18*a*** enclosed except for the mouths **19** of the expansion tubes **3**. The internal structure is supported inside the cylindrical shell by members **20**.



Fig. 4 illustrates the flow system of the pulse jet pump. External air enters the ducts **4** to the centrifugal compressor **5**, into passage **21**, through vane slit openings **22**, past fuel jets **23**, supplied from pipe system **54** through turbulence-inducing meshes **24** in premixing chambers **6**, around baffles **25**, through opening **26** into passage **27**, where if the rotary arm air cushion feed **7** is out of the way, the premixed charge passes through duct **27*a***, valve **8** when open, and into firing chambers **9**. Other compressed air in passage **21** passes through valve slit openings **28** in the blade disc of turbine **1**, past detonating-fuel jet **29** through turbulence-inducing screens **30** into annular chamber **31**, and if the rotary arm of the air-cushion feed **7** is out of the way it enters duct **32** and through valve **8** (when open) so that the premixed detonating fuel is found in the section **9*a*** of the firing chamber **9**. As soon as the main portions of the firing chambers **9** are filled with premixed fuel and air, and the region **9*a*** is filled with the premixed detonating fuel and air at the edge of the firing chamber next to the spark plugs **35** (Fig. 22), the arms of the air cushion feed **7** close the entrances to ducts **27*a*** and **32**, and allow a cushion of compressed air to flow through valve **8** just before it closes, ready for firing. The compressed air for the cushion air feed **7** has come from holes **33** in the hollow axle **15** supplied from holes **34** from the passage **21**. Fig. 22 shows a vertical section of the edge of the firing chamber containing the row of spark plugs **35**. The alloy steel walls **36** and **37** (Fig. 23) form a cooling jacket for the circulation of fuel around the firing chambers **9** before it is forced out of jets **23**. The inner surfaces of the firing chambers **9** are lined with a thin layer of refractory material **38** such as a ceramic.

Fig. 24 shows a vertical section of a spark plug **35**. The electrodes **39** are mounted in a refractory insulator **40** such as porcelain which is recessed below the surface of the firing chamber wall **36** to form a protecting pocket of air not swept out by the filling fuel and air mixture, and are cooled by the flow of fuel from tube **41** and that flows out through tube **42**, the fuel lines and electrical connections being brought to the fuel chambers 9 through the conduits 44 and 43 in Fig. 4. The special fuel-air mixture (such as air and acetylene or methane) in the vicinity of the spark plugs is detonated by the line of spark plugs 35, and a high velocity combustion shock wave travels laterally across a firing chamber so rapidly that no appreciable amount of the combustion products can escape through throat 68 into an expansion tube 3 during the explosion, which thus occurs at constant volume with the maximum pressure and temperature required for a high thermal efficiency in any heat engine. The compressed air admitted through valve 8, just before it closed, by the air cushion feed arms 7, acts as a thermal barrier to protect the rotary disc valve 8 from the full heat of the explosion. After the firing of chambers 9, slugs of high pressure, high velocity combustion products escape into the expansion tubes 3, and impact against lower velocity air in the expansion tubes 3 with supersonic velocity. The fronts of the slugs 47 of combustion gases are normal shock waves that compress the air that they overtake and add it to the high velocity slug of combustion products, which travels down the combustion tubes 3 at a velocity somewhat less than that of the shock fronts. The inlet valves 10 to the expansion tubes 3 have no moving parts and their detailed action is illustrated in Figs. 14 through 18. For the illustration of the general flow pattern it is sufficient to note when the head of a high pressure, high velocity slug of gas and air passes a valve 10, it starts to expand and deflect toward the openings 45 (Fig. 4), but is intercepted by outer vanes 46 and directed back into the expansion tubes 3. After a high velocity slug 47f to 47b has passed, its momentum produces a partial vacuum in its wake, and air rushes into expansion tubes 3 through openings 45 from the low pressure chamber 2. The front of the slug 47f is shown as having overtaken and combined with the rear of the preceding slug 48b, producing a nearly steady pressure and velocity exhaust from the mouths 19 of the generally pyramidal expansion tubes 3. The succeeding high velocity slug will in turn compress the air that is pulled into the expansion tubes 3 in the wake of the slug 47f to 47b. The reduced pressure in chamber 2 causes external air to flow in air ducts 11. The amount of air flow through the turbine 1 is regulated by variable length, telescoping cylindrical vanes 12, the position of the outer one being determined by a cable 49, one end of which is attached to the inner edge and one end to the outer edge of the extended cylinder. The cable 49 is driven by drum 50 on servomotor 51. Stationary vanes 52 direct the air through the turbine vanes 53. The turbine 1 drives the centrifugal compressor 5 through conventional gears (not shown) in box 13.

For detailed consideration of rotary valve 8 and air cushion feed 7, preference is made to Fig. 5 and to Fig. 7, a horizontal section along line 7—7 in Fig. 2 or Fig. 5. The main axle 15 mounts the arms of the air-cushion feed 7 which secures drum rim 55 to carry a disc valve 8 as it slides between plates 56 and 57. The disc valve 8 is thin and flexible so that perfect alignment is not required over an extended surface, it being kept taut by an inner ring 58 which is bolted to the inner edge of the disc. The disc valve 8 rotates in ball bearings 58a which lie in grooves 59 in the much thicker plates 56 and 57, these being attached to a stationary tube 60 which is carried by the supporting plate 61. Valve 8 is shown open to allow flow of gaseous charge into the firing chamber 9. Valve 8 is shown closed in Fig. 21 which is a horizontal section along line 21—21 in Fig. 13. Figs. 13 and 13a are the same as Fig. 7 except that they show one closed and one open position respectively of valve 8, without interference from the airfeed arm 7. The duct 27a leads to the duct 63 in a plate 56 and to the duct 62 in plate 57 which acts as the head of the rectangular cross section firing chamber 9 with its fuel cooling jacket 66. Rollers 64 prevent the excessive wear that would otherwise occur if the edges 67 were deflected inward by the pressure against an edge of duct 62 or 63. The edges 67 may be set for the desired small clearance at the ducts 63 and 62 by adjustable bearings 64a (Fig. 7), before the assembly of valve 8, by first adjusting the rollers 64, the bearings 64a of which are mounted in the plate 57. The disc of valve 8 is moved against the rollers 64 by sliding the drum rim 55 to the right. Rollers 64 (mounted on bearings 64a in plate 56) are then adjusted against the disc of valve 8 by sliding plate 56 and projection 69 over the tube 60 and support 70 respectively then locking projection 69 to support 70 by conventional means. Oil pressure feeds 65 (Fig. 21) provide a continuous oil film which with the small clearance of the rollers 64, prevents after an explosion the escape of appreciable amounts of the high pressure air cushion compressed in the head 62 of the firing chamber 9. As the head 62 and firing chamber 9 are very narrow, the high strength alloy steel valve blade of valve 8 is not bent sufficiently into the duct 63 to exceed its elastic limit. The thermal loss to the cooling fuel jackets 66 is not high because the combustion products only remain in the firing chamber 9 for a few thousandths of a second, the combustion products passing from the throat 68 (Fig. 4) into the expansion tubes 3 (see Fig. 6) at whatever the velocity of sound may be for the elevated temperature at the throats 68. The cylindrical bottom 69 of duct 27a is supported by the disc 70 mounted on the tube 60.

In Fig. 6 is it shown that there are preferably four expansion tubes 3 held concentrically within the shell 18 and surrounded by the low-pressure air space 2. The mounting or spacing members for the tubes 3 are 20 while their combustion chambers are supported by extensions of the plate 61. Plates 61 and 18a support a hollow tube 60 which does not revolve. It is coaxial with the axle 15, which however, is too short to contact the tube 60. Within the double walled combustion or firing chambers 9, the row of spark plugs 35 are seen to extend. The electronic controls, including the ignition current supply is housed within the boxes E at one side of the flaring rectangular outer ends of the expansion tubes 3. These ends are supported in apertures in the plate 18a. A row of six inlet valves 10 formed in part by outer vanes 46 is shown for illustration only; these valves may have a form modified from that shown or may be present in a different number.

The valve 8 and air cushion feed 7 are shown in greater detail in Figs. 8 through 13.

Fig. 9 is a vertical section along line 9—9 in Fig. 7 and shows the four entrance ducts 62 to the four firing chambers 9, the support 61, the expansion tubes 3 and the inflowing air 3a along their sides in dashed lines. The four blades of rotary valve 8 are shown to one side of the firing chamber entrance ducts 62 corresponding to the open position of the valve 8. The blades 71 are drawn taut between the drum rim 55 and the ring 58 which slides in groove 59 (Fig. 4) in plates 56 and 57 which are supported by the tube 60 and support 61.

Fig. 8 is a vertical section along line 8—8 in Fig. 7 and shows the four ducts 63 in the plate 56, the rotating rim 55 separated from the fixed plate 56 by the annular space 73. The end of the ring 58 is shown in the groove 59, plate 56 being supported by tube 60.

Fig. 10 is a vertical section along line 10—10 in Fig. 7. The rotating drum 55 is separated from the stationary plate 74 by the annular space 73. The ends of the four ducts 27*a* in the plate 74 are extensions of the four ducts 63 in the plate 56; plate 74 being supported by the fixed cylinder 69.

Fig. 11 is a vertical section of the air cushion feed 7 along the line 11—11 in Fig. 7. Mounted on the axle 15 is the disc 75 which forms a back wall for the inner portions 76 of the four air feed arm channels 77 that receive compressed air through holes 78 and outer parts 79 of which slide on the face plate 74. When the air feeder arm channels 77 are opposite the four ducts 27*a*, compressed air flows through the feeder channels 77 into the ducts 27*a*. At all other times the premixed charges of fuel and air in chamber 27, and the premixed charge of air and detonatable fuel in chamber 31 are free to flow into the ducts 27*a* leading to the valve 8. The outer ends of the channels 77 are secured to the edge of the rim 80 which supports drum rim 55.

Fig. 12 is a vertical section along line 12—12 in Fig. 7. The outer rim 80 of the four rotating arms of the air cushion feed 7 support the drum rim 55. The edge of the wall 81 of the low pressure chamber 2 makes sliding contact with the rim 55 (Fig. 7). The inner ends 76 of air feed channels 77 are attached to plate 75 and receive compressed air from axle 15 as shown more clearly in Fig. 7. The outer parts 79 of compressed air feed channels 77 ride over plate 74, and supply compressed air to ducts 27*a* when they pass over them.

Figs. 13 and 13*a* show horizontal sections of two different phases of the valve 8 and feeder 7 of Fig. 7. In Fig. 13*a* the valve 8 is open and the air feeder channel 77 is not covering the ducts 27*a*, so that premixed fuels and air pass from passages 27 and 31 in Fig. 4 into the ducts 62 that form the heads for the firing chambers 9. In Fig. 7 the air feeder channels 77 have covered the passages 27 cutting off the supply of premixed fuels and air, and supplying compressed air into ducts 27*a* and through valve 8 to firing chamber heads 62. In Fig. 13, valve 8 has closed ready for the firing of chambers 9, and the air feeder channels 77 have cleared the ducts 27*a*, allowing premixed fuels and air again to flow into ducts 27*a* preparatory to the opening of valves 8 for the next firing cycle.

Figs. 14 through 18 are schematic drawings to illustrate the action of the valves 10 (Figs. 2 and 4) that prevent the escape of the high pressure, high velocity air and gas slug from the expansion tubes 3 into the low pressure chamber 2, but when the pressure in the expansion tubes is reduced in the wake of a slug of gas and air, allow free flow of air from chamber 2 into the expansion tubes 3. As the inlet valves are symmetrical with respect to the two long sides of the



cross-section of the expansion tubes 3, only one side is shown. Fig. 14 illustrates the action of the valves 10 when there is a high pressure, high velocity flow of air and gas down the expansion tube 3. The supersonic flow expands at supersonic valve 10*a* into a Prandtl-Meyer flow around the corner surface 82 in the general direction of the arrow 83, the outer portion of this flow striking the surface of outer vane 84 approximately tangentially. Outer vane 84 is curved in the direction to deflect the flow back into the expansion tube 3 with the normal cross section at the next valve corner 82. The specially shaped surfaces 102*a* and 102*b* (Fig. 19*a*) of guard vanes 86 are designed to reflect expansion waves from corner 82 to the surfaces of vanes 84 and thus prevent the formation of oblique shocks that would otherwise occur at this surface. At the corner 82′ the air flow has been slowed to subsonic velocity, and no shocks can be formed. The outer vanes 84 are shaped to be tangential to the flow expanding across the openings 87 in the subsonic inlet valves 10*b*, so that a smooth flow is obtained without undue turbulence.

Fig. 15 shows the air in low pressure chamber 2 rushing into expansion tube 3 through valves 10 to fill a low pressure volume in the wake of a compressed air and gas slug. The air as indicated by arrows 88 enters at only a small angle to the wall of expansion tube 3, and at the valve 10*a* nearest the firing chamber 9 the flow may temporarily be toward the firing chamber as indicated by arrow 89.

Fig. 16 shows an initial slug of gas and air $47_1$ with normal shock front $F_1$ still traveling somewhat above sonic velocity into the still air ahead, although the air and gas on the left, high pressure side of the shock front $F_1$ travels at a velocity greatly below transonic values. The same pressures and relative velocity would exist if the front $F_1$ were stationary and the air on the right were approaching it at the supersonic velocity $V_1$ not very far above sonic value. After passing the normal shock point the air velocity would be reduced somewhat below the sonic value, but would have a relative velocity to the stationary front $F_1$ of nearly sonic value. Hence the relative velocity of the front $F_1$ actually moving with greater than sonic velocity must be in the neighborhood of the velocity of sound, or the velocity of the air on the high pressure side of the shock $F_1$ must be a relatively low value as hundreds of feet per second. The pressure $P_1$ on the left of the shock front $F_1$ may be very high compared to $P_0$, the atmospheric pressure for the still air ahead. The rear of the slug $47_1$ is not sharp as indicated by $R_1$ for the purpose of illustration, but is somewhat diffuse, although the bulk of the gas and air once belonging to the slug can be contained within two boundaries such as $F_1$ and $R_1$. The shock front $F_1$ can only exist for a definite set of pressure, density, and velocity ratios of the fluid on its rear and front sides. The pressure $P_1$ must also equal the static average pressure inside the slug 47 as given by the equation of state plus the pressure produced by virtue of the rate of decrease of momentum of the slug as its velocity decreases from impacting the still air ahead. The pressure $P_1$ at the rear of the slug $47_1$ has a pressure equal to the average static value minus the change in pressure produced by the rate of decrease of momentum of the slug. There is a pressure gradient from the front to rear of the slug. Thus the portions of the slug passing valves 10b have sufficient pressure to prevent the flow of air from the chamber 2 into the expansion tube 3. At valve 10a, however, at the rear of slug $47_1$ the pressure has been reduced to a value allowing influx of air from chamber 2, and air is forced to follow in the wake of $R_1$ under a sufficient pressure differential to maintain its flow.

Fig. 17 represents the flow diagram one firing period later, the firing period being the time between consecutive shots (explosions) from the firing chamber 9. The front $F_1$ of the first slug $47_1$ has now reached the mouth 19 of the expansion tube 3, and if no slugs had followed it, its rear position would be at $R_1$. Actually the second slug $47_2$ overtakes the rear of the first slug $47_1$, and has its shock front at $F_2$ and its rear at $R_2$. The second slug $47_2$ has traveled faster than the first slug $47_1$ as its impacted air already moving with fair velocity in the wake of slug $47_1$.

In Fig. 16 the front $F_2$ of the second slug $47_2$ has reached the mouth 19 of expansion tube 3, and the third slug $47_3$ would have advanced its front $F_3$ to the position shown if it had not impacted the rear of the second slug $47_2$. $F_3$ is illustrated as being slightly beyond the position of $F_2$ one firing period earlier because the air ahead of it was moving faster than that ahead of $F_2$. This change is small however, and in a few cycles the slug position pattern has reached the steady state condition which is approximated by Fig. 18. The action of a given slug in overlapping the rear of a preceding slug causes an averaging of the low pressure of the rear of the preceding slug and the higher pressure of the head of the following slug, so that the exhaust pressure and velocity from a mouth 19 do not have large variations. The presence of two or more slugs in the flow system at one time allows a relatively high frequency firing rate, e. g., 200 explosions per firing chamber per second and greatly increases the capacity of the pump. Small pressure fluctuations from the exhaust mouths 19 are of a frequency that can readily be eliminated by the use of storage tanks each having a volume only a fraction of that of expansion tubes 3. Because the mouths of the expansion tubes 19 are in parallel, and because they fire in sequence, the pressure fluctuation at their exhausts is still further reduced.

Figs. 19 and 19a are schematic diagrams of the expansion waves in a supersonic valve 10a in an expansion tube 3. The expansion tube has a rectangular cross section of two opposite sides of constant length to produce an approximate two dimensional flow. Fig. 19 represents the flow pattern for the relatively low velocity rear end of a slug of compressed gas and air passing a supersonic valve 10a as it expands down tube 3, while Fig. 17a represents the flow at the same valve 10a for the relatively high velocity front end of the slug. The flow is somewhat similar to the familiar case of the jet in Fig. 20 flowing from orifice 96 into a region of lower pressure indicated by point 85. Since the jet is symmetrical about the trace O—O' of a plane perpendicular to the plane of the figure, the flow pattern would be unaffected by the insertion of a very thin solid boundary along the above plane of symmetry. The upper half of the flow pattern need only be considered. A Prandtl-Meyer expansion starts around corner 90 with the generation of the expansion waves 91 which are reflected from the solid boundary along O—O' to the free upper boundary at 93. These expansion waves are reflected from the free upper jet boundary as compression waves 94 that reflect from solid boundary O—O' at 95 to form compression shocks at cusps 97. In the Figs. 19 and 19a the guard vane 86 separates the flow of the peripheral part of the slug passing down expansion tube 3 past the opening 87 in the supersonic valve 10a, from the flow of the interior portions, thus preventing the spread of turbulence from the peripheral to the inner regions. The peripheral flow, which is parallel to the flat wall 98 of the expansion tube 3, starts a Prandtl-Meyer expansion around the corner 82 which deflects the outer flow across the opening 87 along the arrow 83. This flow has tangential incidence along the outer vane 84 which curves down until at point 99, it is tangential to and on the boundary of expansion tube 3. Expansion waves such as *a*, *b*, *c*, *d*, *e*, and *f* spread out from corner 82 and if the vanes 86 and 84 were not present the flow line 100 would follow the dotted line 101 in a free expansion around corner 82. The expansion waves are actually, however, reflected from the surface 102 of guard vane 86 as expansion waves such as *a'*, *b'*, *c'*, *d'*, *e'* and *f'* (Fig. 19) with slopes of opposite sign from those of *a*, *b*, *c*, *d*, *e* and *f* and which deflect the flow back toward the boundary of expansion tube 3. Shock waves have no tendency to form along the surface 102 as the upper curvature is less than that occurring for free expansion around corner 82. If the outer vane 84 deflected the flow downward, oblique shocks would form along its lower surface, but these incipient shocks are cancelled by the incidence of expansion waves such as *a'*, *b'*, *c'*, *d'*, *e'* and *f'* which deflect the flow downward. The outer vane 84 is needed to prevent the turbulence that would result between the boundary of a high velocity flow and a region of stationary air that would result if a solid boundary were not present. The surface 102a is specifically shaped to bring the expansion (reflected) waves to the proper points to cancel out the incipient oblique shocks along the lower surface of outer vane 84. The flow patterns of the front and rear of the supersonic slug do not differ enough for the same geometry of vanes 84 and 86 as illustrated in Figs. 17 and 17a to cause more than weak oblique shocks from lack of complete cancellation of shocks by the expansion waves. Pressure recovery loss due to turbulence is thus kept a minimum.

Fig. 15 illustrates the action of the valves 10a when the pressure in the expansion chamber is less than in the chamber 2. The air then flows in at subsonic velocity with the minimum of turbulence, the small scale turbulence around the vane tips 103 being localized.

The utility of the various electronic sections shown in Fig. 25 and divided by dotted lines may be stated as follows:

*Section A.*—Photoelectric means of producing a firing spark after the closing of valve 8. Delivery of a number of equal voltage pulses to part C equal to the firing frequency.

*Section B.*—Establishment of a reference firing frequency that may be modified by pressure correction circuits in part E.

*Section C.*—Comparison of the actual firing frequency and reference frequency, the difference being used as a correction to the position of the vane 12 in regulating the speed of the turbine 1 to bring the firing frequency back to the reference value.

*Section D.*—Circuits to provide a voltage proportional to the pressure measured by pickoff 183 in expansion tubes 3.

*Section E.*—Pressure correction circuits to regulate the frequency of reference oscillator 143 to a value to maintain the output pressure at the desired reference value.

*Section F.*—To keep the speed of the fuel pump motor proportional to the reference and firing frequencies.

In the schematic circuit drawing of Fig. 25 in section A, a pickoff wheel 121 is coaxial with the blades of the valve 8, and is contained in the auxiliary box 13 of Figs. 2 and 4. Valve 8 has just closed the duct 62 (in Fig. 10) to the firing chamber 9, and the spoke 122 (Fig. 25) of the test pickoff wheel 121 has just interrupted a light beam 123 from a light source 124, which beam is prevented from reaching the photocell detector 125. Thus, when the firing chamber 9 has been charged with an explosive mixture through duct 62, and the valve 8 has closed ready for firing, the interruption of the light beam 123 by the spoke 122 suddenly stops the D. C. current flow in the primary 126 of transformer 127 which is in series with a self-generating photoelectric cell 125. The sudden stoppage of D. C. current in the primary 126 produces a voltage pulse in the transformer secondary 128. The current pulse produced in the secondary 128 is of the correct polarity when the light beam 123 is interrupted to flow through the rectifier 129. On the contrary, the current pulse produced in the secondary 128 will not be of the proper polarity when the beam 123 is uncovered by the spoke 122, thus preventing sparking except when the valve 8 has just been closed. A resistor 130 is in series with the rectifier 129 and the secondary coil 128, and the voltage across it is impressed on an audio amplifier 131 which is tuned approximately to the fundamental of the pulse from resistor 130. The output of an amplifier 131 is in series with the primary of a transformer 141 and an input thyratron 132. The thyratron 132 is in series with the primaries of transformers 134 and 139, and a condenser 135 which may be charged by a D. C. source 136 through a small fixed resistor 137 and a tube 138. When a voltage pulse is received from the amplifier 131 on the input of the thyratron 132, the thyratron 132 fires and discharges the condenser 135 through the primaries of transformers 134 and 139. Such action causes a firing spark for chamber 9 to appear at gap 140. In order to measure the firing frequency by an integration process, it is necessary that the voltage pulses across transformer 134 all be alike. This is partly achieved by designing transformer 134 so that its core is saturable at each pulse, but since the knee of the magnetization curve is never really sharp, it is in addition necessary to insure that the condenser 135 is charged very nearly to the same voltage before each discharge. This requires a rapid charging rate for condenser 135, and to effect this result the voltage source 136 is impressed in series with the small fixed resistor 137, the condenser 135, and a variable impedance tube 138 which normally has a very low impedance. Therefore the charging rate of the condenser 135 is very rapid except for a short period at the breakdown of the thyratron 132. The pulse which fires the thyratron impresses a voltage on transformer 141 that is transmitted through a rectifier 149 to a capacity-resistance network 142 the time constant of which is adjusted to the desired short period. The voltage across this network biases the tube 138 to cutoff. Therefore the voltage from D. C. source 136 cannot prevent the thyratron 132 from reopening when the voltage on the condenser 135 normally passes through zero because the condenser 135 is then separated from D. C. source 136 by the high impedance of tube 138. A rectifier 149 prevents a decrease of the pulse voltage from the amplifier 131 from opening the tube 138.

Section B of Fig. 25 has the function of producing a series of pulses of a frequency determined by a sawtooth oscillator 143 which is used as reference. The output of the oscillator 143 is connected to trigger the thyratron 144, which is in series with the primary coils of transformers 145, 146 and 264—265, and condenser 147. The transformer 145 is designed for core saturation on each pulse-discharge through the thyratron 144. To insure that the number of voltage pulses on transformer 145 can be recorded by integration of the separate pulses, these pulses are made further alike by a circuit able to charge condenser 147 very rapidly to the full voltage of D. C. source 136. Voltage source 136 is in series with a low resistance fixed resistor 149, the variable impedance tube 150, the primary of transformer 264—265 and condenser 147. At the instant the thyratron 144 is fired by a pulse from oscillator 143, the secondary 265 of transformer 264—265 which is in series with a rectifier 151 impresses a voltage pulse on the latter and the capacity resistance network 152 which is in parallel with the input of tube 150. For a short period at the time of firing thyratron 144, determined by the time constant of the capacity-resistance network 152, the tube 150 is biased to cutoff, thus giving the thyratron 144 opportunity to open as the condenser 147 discharges to zero voltage. The rectifier 151 allows passage of only such voltage polarity from the transformer 148 as will bias tube 150 toward cutoff.

Section C of Fig. 25 shows the circuit for controlling the turbine speed, and since the turbine 1 is mounted on the same shaft as the valve 8, the loading of firing chambers 9 is controlled by the turbine speed. It was shown in the description of section A that the firing frequency was controlled by the speed of rotation of the blades of valve 8. It is the function of the circuit in section C to compare the actual frequency of firing pulses received on leads 153 from transformer 134 with the number of voltage pulses on leads 154 coming from transformer 145, which are equal to the frequency of the reference oscillator 143. The firing-voltage pulses from leads 153 are in series with the rectifier 155, condenser 156, and the variable resistor 157. The reference voltage pulses on leads 154 are in series with variable resistor 158, rectifier 159 and condenser 160. Resistors 157 and 158 may be adjusted to a point at which, for an equal number of firing and reference pulses, the voltages on condensers 156 and 160 are equal. The resistor 161 is in parallel with condenser 156, and resistor 162 is in parallel with condenser 160. Since the condenser voltages are of opposing polarity, the voltage to the input amplifier 163 will be zero when the condensers 156 and 160 are charged to voltages of equal magnitude; the firing and reference frequencies then being equal. If the firing frequency is different from the reference frequency, a voltage will be impressed on the amplifier 163 to operate the solenoid switch 164. For this switch the center position of the armature contactor 165 corresponds to zero solenoid current. The D. C. voltage source 166 is impressed upon the resistors 167 and 168 in series, leads from the midpoint 169 of resistors 168 and 167 and the contactor 165 going to the servomotor 51. On the servomotor 51 is mounted the grooved drum 50 which is wrapped by one loop of cable 49 which, as previously mentioned, pulls the cylindrical vane 12 (Fig. 11) in or out to control the air intake and speed of the turbine 1. If the firing frequency exceeds the reference frequency, the contactor 165 is pulled to contact 170, and contactor 165 is then electrically negative to point 169 between resistors 168 and 167, and the servomotor drum cable control pulls the vane 12 farther forward. Less air, is thus intercepted and the turbine speed is reduced. If the firing frequency is less than the reference frequency, the contactor 165 is pulled to contact 171, and the servomotor 51 is rotated in such a direction as to cause vane 12 to intercept more air, thus increasing the speed of turbine 1 until the firing frequency is equal to the reference frequency.

The circuit of section D of Fig. 23 has the function of maintaining the speed of the fuel pump motor 177 proportional to the firing frequency, which is kept equal to the reference frequency. As will be later explained, the reference frequency may be changed automatically to keep the exhaust pressure of the pump at a desired value. Every reference voltage pulse actuates the transformer 146 which impresses a voltage pulse on the A. C. amplifier 172 the output of which is in series with a rectifier 173 and a condenser 174. The condenser 174 is in series with a resistor 175 and a D. C. generator 176 which is connected to the shaft of the fuel motor 177. As the voltages on the condenser 174 and the generator 176 have opposite polarities, no current will flow in the resistor 175 when the speed of the fuel pump motor 177 has the correct value for a given reference frequency; the gain of the amplifier 172 having been adjusted to the correct value in the initial calibration. Opposite voltage polarities will appear across the resistor 175 when the speed of the motor 177 is greater or less than its proper value. The speed of motor 177 is controlled by a variable solenoid 178, the impedance of which is in series with the armature of the motor 177. The position of a solenoid plunger 179 is determined by the pull of the cable 180 which runs over pulleys 181 and 182. Pulley 181 is mounted on the shaft of servomotor 183 which has opposite directions of rotation for voltages of opposite polarity on resistor 175.

Section E of Fig. 25 shows a circuit for producing a D. C. voltage proportional to the exhaust pressure in the expansion tubes 3. A tube 183 leads from the exhaust ends of expansion tubes 3 to a bellows box 184 which is divided by a diaphragm 185. A compartment 186 of the box 184 on the lower side of a diaphragm 185 is evacuated. Differences in the exhaust pressure of the expansion tubes 3 cause the diaphragm 185 to move in or out with proportional displacement. The displacement actuates a lever system 187 to slide the contactor 188 along a potentiometer 189 which is in parallel with a D. C. source 190, thus giving a voltage on leads 191 which is proportional to the exhaust pressure of expansion tubes 3.

The section F of Fig. 25 shows a circuit for changing the reference frequency of the sawtooth oscillator 143 (and hence also the firing frequency, which is kept equal to the reference frequency) so as to maintain the exhaust pressure of expansion tubes 3 at the desired value. The voltage on the leads 191 is bucked against the I. R. drop of a resistor 192 which is controlled by a D. C. source 193 and a variable resistor 194 to equal the voltage of the leads 191 for the desired exhaust pressure of expansion tubes 3. If the exhaust pressure of tubes 3 is different from the desired reference value, an error voltage appears across the resistor 195, the polarity of which depends upon the sign of the error and the magnitude of which depends upon the amount by which the pressure has departed from the desired value. This error voltage is impressed on the leads 196 and upon the input of two conventional triode circuits, the components of which are connected as follows: The given error voltage polarity is impressed across the grid and cathode of one tube 197, and across the grid and cathode of another tube 198; the rectifiers 199 and 200 preventing error signal current through grid leaks 201 and 202 respectively, unless the polarity on the grid is such as to increase the plate current. Therefore, regardless of the polarity of the error voltage, one tube will always have an increased plate current and there will be no change in the plate current of the other. The leads 206 are taken across the plate resistors 203 of the tube 197 and 204 of the tube 198 in series with a decoupling resistor 205. When no error voltage is impressed on tubes 197 and 198, the output voltage on leads 206 is balanced out by the voltage across resistor 207 which is supplied by a D. C. source 208 through a control resistor 209. The voltage across the leads 210 is thus proportional to the magnitude of the error voltage regardless of its polarity, and is impressed across a resistor 211 which forms part of the input to an amplifier 212 which furnishes the correction voltage to be transmitted to a reference oscillator, as later described.

Extensions of the leads 206 are impressed across a grid resistor 214 on the input of a tube 215 which with a conventional circuit and condenser signal pickoff 216, supplies a voltage to the output leads 217 which is proportional to the time differential of the input, i. e., to the time rate of change of the magnitude of the error voltage, regardless of its polarity. A rectifier 218 allows a voltage to be put on a capacity-resistance network 219, so that the voltage on leads 220 biases a tube 221 toward cutoff with a large increase in its impedance when the magnitude of the error voltage decreases. This effect greatly reduces the output of a tube 222 which is connected to a resistor 223, when the magnitude of the error voltage is decreasing. Since the input of the tube 222 comes from the leads 191 the voltage of which was shown in the description of section E, Fig. 25, to be proportional to the exhaust pressure of the expansion tubes 3, and since the tube 222 is used in a conventional circuit for differentiating this input signal, the voltage across the resistor 223 is proportional to the time rate of change of the exhaust pressure of tubes 3. When the tube 221 has a low impedance, i. e., when the magnitude of the error voltage is increasing, this condition results in a strong signal on resistor 223, but when the magnitude of the error voltage is decreasing, tube 221 is biased toward cutoff, has a high impedance, and the signal across resistor 223 can be made as weak as desired. This is accomplished by the setting of the variable resistor 224 in the capacity-resistance network 219.

The diodes **225** and **226** are connected across the ends of the resistor **223** so that regardless of the polarity of the I. R. drop across the resistor **223**, the diode on the positive end allows current to flow through the resistor **227**, the I. R. drop across resistor **227** always being in the same direction, regardless of which diode passes current through it. The voltage across the resistor **227** is impressed across the resistor **228** which is part of the input potential to amplifier **212**, and represents the magnitude of the time rate of change of the exhaust pressure of expansion tubes **3**. The other component of the input voltage to the amplifier **212**, is, as before described, the I. R. drop across resistor **211**, which is always of a polarity to aid that across resistor **228**, and is proportional to the magnitude of the error voltage. The combined input to the amplifier **212** thus consists of voltages proportional to the sum of the time rate of change of the magnitude of the exhaust pressure of expansion tubes **3** and the magnitude of the error voltage which represents the amount by which the exhaust pressure of expansion tubes 3 differs from the desired reference value. The component representing the time rate of change of the magnitude of the exhaust pressure in the expansion tubes **3** is weaker for a decreasing than for an increasing magnitude of the error voltage. The output of amplifier **212** constitutes a correction signal which is to be applied to the reference frequency oscillator **143**. The signal value depends both on the pressure error and the magnitude of the time rate of change of the pressure. Very rapid fluctuations in pressure may occur at the start of a supersonic pulse jet pump in which the firing frequency depends upon turbine velocity. It is necessary to anticipate pressure errors before they become large, by the time rate of pressure magnitude changes. However, the correction due to the time rate of change in pressure magnitude is blanked out as much as desired by the tube **221** when the magnitude of the error voltage is decreasing, in order to prevent overshoot and oscillations about the zero point. In order to further prevent overshoot and oscillation about the point of zero correctin voltage, a tube **229** is provided to bias the D. C. amplifier **230** to cutoff when the magnitude of the correction voltage is less than a small value controlled by the negative bias given by the potentiometer **231** which is connected in series with the grid of the tube **229**. When the magnitude of the correction voltage on the leads **210** exceeds the negative bias from the potentiometer **231**, the I. R. drop on the resistor **232** increases very rapidly since tube **229** has a large amplification. Current therefore tends to flow through rectifier **233** in the inverse direction. As this flow is prevented by the rectifier, the input to the amplifier **230** from the amplifier **212** is unaffected by the circuit of tube **229** as long as the error voltage exceeds the small voltage on the grid of tube **229** from the potentiometer **231**. But when the magnitude of the error voltage is appreciably below the negative bias provided by potentiometer **231**, the current through the tube **229** is markedly decreased, and the I. R. drop on the resistor **232** is considerably decreased. Current flows through the rectifier **233**, the direction of current flow through the secondary **265** as previously caused by the amplifier **212**, being reversed, the current being of a value sufficient to bias the input of amplifier **230** to cutoff. Amplifiers **212** and **230** are adapted to handle D. C in order to pass a correction signal which slowly increases due to a very small drift in pressure. The output of amplifier **230** is impressed across the armature contactors **234** of switch **235**, the control solenoid **236** being actuated from leads **237** which are extensions of leads **196**, and are positioned across the error voltage. Therefore, when the exhaust pressure of the expansion tubes **3** is greater than the reference value, the contactors **234** close the circuit on the right hand side, and if the contactors **239** of second reversing switch **238** are also on the right hand side, a voltage will be impressed on a field coil of motor **240** in such a direction as to reduce the reference frequency and to cause a decrease in pressure to the reference value. If the exhaust pressure of expansion tubes **3** is less than the reference value, the error voltage will have the opposite sign. The solenoid **236** of switch **235** will pull contactors **234** to the left hand contacts, reversing the polarity of the correction current of switch **235**. If the contactors **239** of second reversing switch **238** still make contact in the right hand position, the motor **240** will now be speeded up, the reference frequency will increase, and the exhaust pressure of the expansion tubes **3** will rise until it is equal to the reference value.

The function of the second reversing switch **238** is to provide the correct correction voltages to the motor **240** for operating conditions that occur such that the pressure-frequency curve is a double-valued function as in Fig. 26 where points A and B both have a value of exhaust pressure equal to that of the reference. It is preferable that the operating pressure be limited to small oscillations about the point A as the corresponding operating parameters lead to a higher efficiency than for point B. It is therefore desirable to provide second reversing switch **238** and its controlling solenoid **255** to reverse the polarity of the correction voltage to motor **240** when the slope of the pressure vs. frequency curve (Fig. 26) changes sign, corresponding to a pressure between points C and B (pressure greater than the reference). The normal correction is then reversed so that the frequency will decrease and the pressure increase until the maximum at C is reached, when a slight overshoot will carry the pressure into the region for normal operation. Reversing switch **238** is then being actuated by the change in slope so that the frequency will continue to decrease until the pressure reaches the reference value at point A. In starting the jet pump, the pressure and frequency build up together, the more firing shots per second the greater will be the volume of air sucked from chamber **2** through valves **10** into the expansion tubes **3**. The greater the flow of air from chamber **2**, the greater will be the turbine speed for the same setting of the inlet vane **12**. However, the firing frequency may reach a value for which the slugs passing down expansion tubes **3** are too close together for an adequate inflow of air from chamber **2** into the space between them. In such case a maximum in the exhaust pressure is reached at some point C, Fig. 26, but the frequency can still increase by reason of an increased speed of the compressor **5** and valve **8** and by virtue of a change in position of vane **12** to direct more air through the turbine blades. If the reference pressure desired is close to the maximum pressure C, fluctuations might drive the point of operation onto that portion of the pressure vs. frequency characteristic in which the curve has a negative slope. Supersonic flow is sensitive to changes in operational factors such as the efficiency of the compressor 5, and some fluctuation about the reference pressure is to be expected on starting the jet even with automatic control. It is therefore necessary in order to obtain some desired exhaust pressures, to automatically reverse the position of switch 238 upon change in sign of the slope of the pressure vs. frequency curve. Mathematically expressed, when $dP$ is the rate of change of pressure, $dF$ the rate of change of frequency, and $dt$ the rate of change of time, the polarity of $dP/dF$ must be detected, but the magnitude is not needed. Then $dP/dF$ equals $dP/dt$ divided by $dF/dt$, and its polarity is positive when $dP/dt$ and $dF/dt$ have the same sign and is negative when they have opposite signs. It is only necessary therefore, to send a current through the solenoid of switch 238 when $dP/dt$ and $dF/dt$ are either both positive or both negative, and to let the spring action of the switch close the contacts on the opposite side when no current passes through the solenoid. Leads 241 pick off a voltage from condenser 156 proportional to the firing frequency and impress it upon the input of a tube 242. A capacity-resistance circuit 243 differentiates the firing frequency with respect to time. A voltage is obtained across the primary of a transformer 244 of the polarity of $dF/dt$. The primary of a transformer 245 receives a voltage from leads 246 which are in series with condensers 268 which are positioned across the I. R. drop of a resistor 269 of the circuit of a tube 267 for taking the time derivative of the voltage, on its input from leads 266 which are across a voltage proportoinal to the expansion tube exhaust pressure. The secondary of transformer 244 is impressed across the input of a tube 247 which is in series with a tube 248 and an output resistance 249, the input of tube 248 being taken across the secondary of transformer 245. A voltage can only appear across the output resistance 249 when both tubes 247 and 248 conduct, i. e., both $dP/dt$ and $dF/dt$ are positive, since the transformer voltages are large enough so that if the input to a tube were negative, it would be biased to cutoff and no current would flow through the resistor 249. A second secondary coil of transformer 244 is impressed on the input of tube 250 in reverse phase so that its grid is positive only when $dF/dt$ is negative. Likewise a second secondary of the transformer 245 is impressed upon the input of a tube 251 in inverse phase, so that its grid is only positive when $dP/dt$ is negative. Thus only when $dF/dt$ and $dP/dt$ are negative, will tubes 250 and 251 pass current through resistor 252. The leads 254 originate across resistors 249 and 252 in series, voltages adding, so that the voltage on leads 254 to solenoid 255, have the same polarity for $dP/dt$ and $dF/dt$ both positive or both negative, but zero voltage if they have opposite polarity. The wiring sense of the solenoid 255 is such that the reversing switch 238 makes contact on the right side if $dP/dF$ is positive and is pulled to the left side contacts by spring action for $dP/dF$ negative. Under such condition, no current flows through the solenoid. The switch thus reverses the polarity of the normal correction voltage when the pressure vs. frequency curve becomes negative, forcing the point of operation back up the slope B–C, past the maximum at C by a small overshoot, with reversal of the reversing switch 238 by the change in slope of the curve as the maximum is passed. Therefore the correction signals are now of the proper polarity to reduce the pressure to the reference value.



To prevent the solenoid 255 from losing its control signal when the frequency drift is too low to be detected by the transformers 244 and 245, the error voltage from leads 196 is amplified by a tube 256, and conducted by leads 257 onto an auxiliary winding coil 258 of the motor 240 in such a direction as to normally start a correction in the pressure until the time rate of change in pressure is sufficiently large to pass the capacity-resistance circuit 243, and then to actuate transformers 244 and 245 so that solenoid 255 will be properly controlled. When this condition is reached, the voltage on leads 259 is great enough that when amplified by a step-up transformer 260, the I. R. drop across a resistor 261 is enough to bias the tube 256 to cutoff and to stop the artificial frequency drift produced by the auxiliary coil 258 of the motor 240. The rectifiers 262 and 263 keep the same polarity across the resistor 261 regardless of which half of the secondary coil of transformer 260 is conducting current for the frequency drift of a given polarity. This effect is produced because the two halves are wound in opposite coil sense, so that their voltage polarities are 180 degrees out of phase for a given voltage impressed on the primary.

*Starting the pulse jet pump or motor*

Starting is accomplished in a manner similar to that of the conventional turbojet engine, the starting motor in container 13, driving the common shaft 15 of the turbine which is geared to the compressor. The pressure pickoff 183 from the expansion tubes registers zero initial pressure above the atmosphere, and calls upon the reference oscillator 143 for a higher frequency of firing, which causes the servomotor 51 to position the cylindrical vane 12 to intercept the maximum designed fraction of the air input through the turbine blades 53, thus increasing the speed of the turbine and compressor as rapidly as possible, and raising the firing frequency. The combustion chambers are fired for every passage of the valve blade 8 past a combustion chamber entrance 62. The firing frequency is thus directly proportional to the speed of the turbine 1 and compressor 5 geared thereto. The compression ratio of the explosive charge is at first low due to the low compressor speed, and the fuel supplied is low in proportion since the speed of the fuel pump motor 177 is maintained directly proportional to that of the firing frequency and the turbine speed. The initial explosions are of low power and not much air is pulled through the valves 10 into the expansion tubes 3, so that the acceleration of the turbine is not aided much by the air pulled through its vanes 1, the main load falling on the starter motor in container 13. As the turbine 1 and compressor 5 pick up speed, however, the compression ratio increases, the frequency of firing increases, the explosions from the combustion chambers 9 are more powerful, more air is sucked from chamber 2 through valve 10 into the expansion tubes 3, and the turbine begins to take a share of the load, and the pressure in the pickoff 183 increases, until finally at full compressor speed, the pressure at said pickoff has reached the reference value. The frequency called for by oscillator 143 has remained at maximum stop position (which e. g., might be 10% above the normal operating value), but as the reference pressure is exceeded and the sign of the pressure error changes, the motor 240 has a reversed torque and starts to decrease the reference frequency called for, and automatic electronic control circuits previously described in relation to Fig. 23 take over, causing the output pressure in expansion tube **3** to decrease smoothly to the reference value. The input to the reference frequency control motor **240** is proportional to the sum of two voltages, one of which is proportional to the magnitude of the pressure error voltage, and the other to the magnitude of the time rate of pressure change modified to be smaller for decreasing pressure errors, the sign of this whole correction being controlled by a relay switch to be of the proper polarity to decrease the pressure error.

Many changes from the exact form of my motor or pump and its control circuits as shown may be made without departing from the spirit of the invention. For example, a form of the casing may be modified as to external shape, the form of the high pressure fuel storage chambers may be modified, the form of the ports in the disk valve may be modified and the expansion tubes may be made funnel shape rather than in the form of a diverging prism.

*Process*

The generalized cycle for producing augmentation of momentum in jet propulsion therefore consists of the following steps divided into three phases, i. e., the explosion phase, the augmentation or impacting phase, and the delivery phase.

1. In the explosion phase there is only a single step, i. e., explosion of a previously prepared mixture of finely divided fuel and air by a high velocity combustion shock produced by the detonation of a separate fuel and air charge produced from a detonating liquid hydrocarbon or other chemical.

2. The augmentation phase comprises six successive steps, which however as a practical matter takes place with such rapidity that they may be regarded almost as a single step. The stages are:

*a.* Discharge of a supersonic slug of gas from the combustion chamber to the expansion tube,
*b.* Impingement of the supersonic slug or gas upon the slower gas in expansion tube,
*c.* Compression of the gas flowing across the shock front of the slug,
*d.* Expansion of the gas in the slug into a volume of lower pressure gas flowing into the slug across its shock front,
*e.* The reaction of the expanding slug against the divergent sides of the expansion tube, and
*f.* The inflow of air or gas in the low pressure wake of the slug to prevent stoppage of a pump or motor by excessive back pressure.

Steps *a* to *f*, inclusive, produce augmentation of momentum by transformation from a small mass, high velocity volume to a large mass, low velocity volume and expansion against the divergent expansion tube walls.

3. Delivery phase.

*a.* Delivery of a large mass, low velocity, low pressure gas flow from the mouth of the expansion tube, and
*b.* A powerful backward thrust on the expansion tube walls during the delivery and augmentation phases.

From consideration of the above generalized method it is evident that a method of generating power either as thrust or suction by bringing about a much larger degree of augmentation due to air entrainment has been provided than has heretofore been known. This improvement has been created by a fundamental change in the steps employed to produce augmentation, thereby differing from the method now generally practiced, i. e., increasing the number of concentric venturi tubes, which soon becomes unwieldly and is always inefficient. My new method is independent of any particular disposition of apparatus and can be carried out with the elements which I have disclosed when these elements are operated, i. e., not compacted into the particular close assembly disclosed, but arranged as separate elements in a series connected by ducts, shafts, etc., after the manner of connected chemical engineering apparatus.

Figs. 27 to 30, inclusive, illustrate the cycle as carried out in the particular case having to do with the pump or motor which I have disclosed. These figures illustrate the cycle as carried out in the sole necessary element, i. e., a flared tube having a single valve for shutting off the cylindrical area of the tubing after ejection of the charge from it so as to provide a backing for the expansion of the slug in the flared portion by reason of its own expansion and by reason of the augmentation which at itself creates by its behavior in the flared end of the tube.

The process can be applied to augment the expansion of a hot slug of gas with a liquid as well as with the gas.

In Figs. 27 to 30, inclusive, a modification of the general fundamental process is shown, augmentation be produced between transformation of a low mass, high velocity slug of gas to a low velocity, large mass of gas by intermittent pulse flow and a minimum of turbulence. The firing, compression, expansion and purging phases are shown in Figs. 27, 28, 29, and 30, respectively. In the firing phase, a hypothetical rotary nozzle expands high pressure gas into a bank of flared tubes to form a low mass, high velocity piston or slug of gas therein. This high velocity impacts against the slower air ahead of it and compresses the air, the valve being open for the expansion of the slow air column through the flared end. In the compression phase, the gas slug has compressed the air ahead of it into a high pressure slug, and the valve has closed behind it. The gas slug, originally moving at supersonic velocity, has produced a partial vacuum behind it and a new column of air has been sucked in to fill this vacuum. In the expansion phase, the compressed gas and air slug in the flared end has just finished its expansion, thereby producing a powerful thrust against the closed valve and against the flared sides of the tube. The vacuum has nearly disappeared due to the forward velocity of the new column of intake air. The purging phase shows the valve open and the intake air column having nearly purged the rear end of the former slug. The cycle is now ready to be repeated by the next passage of the hypothetical rotary nozzle across the intake of the tube. Figs. 31, 32, 32*a* and 33 show the fundamental method as distinguished from the special method used in Figs. 27 to 30, inclusive. It will be observed that the valve shown in Figs. 31, 32, 32*a* and 33 is an inlet valve and not a backing valve. Therefore, the exploding gases must depend largely for backing upon their own mass and inertia rather than on a solid wall at their rear against which they can push. The steps carried out in the fundamental process or cycle have already been listed in tabular form and can readily be related to Figs. 31, 32, 32*a* and 33 through the legends applied to those figures.

What I claim is:

1. In a pulse jet pump or motor, a casing, a turbine driving a rotary air compressing element to supply compressed air for combustion, combustion chambers within said casing to supply in rapid succession explosions at high temperature and pressure to exhaust slugs of gas for thrust or flow purposes, a rotary disc valve adapted to admit fuel and air mixture to said combustion chamber to provide a high frequency, high pressure valve without the vibration and power loss of reciprocating parts, guide plates having long narrow radial ports, said guide plates being located adjacent said disc valve, which is adapted to rotate between said guide plates to close said ports periodically whereby said guide plates carry radial inlet ports for the combustion chambers and serve as guides for flexible rotating valve blades which slide between the guide plates and intercept said ports at periodical intervals, a drive shaft rotatable in said valve and supporting said blades to rotate said valve blade elements, said rotary disc valve and said guide plates, an outer drum rim mounted on said drive shaft to support the outer edges of said flexible valve blades under tension, an inner ring connected to said blades, said blades being attached between said drum rim and said inner ring under tension, said rings being rotatable with said blades, said guide plates being stationary and supported by a stationary tube, and having a groove to receive said ring whereby to form a recess circular channel to carry the ring as it holds the inner edge of the valve blades under tension and rotates with said blades.

2. In a pulse jet pump or motor a substantially cylindrical casing having a forward port, a center shaft and extending through said casing, a base, a front bearing extending upwardly from said base and supporting said shaft, an air compressing impeller mounted upon said shaft to furnish compressed air for combustion, a combustion chamber to furnish high temperature, high pressure slugs of gas, an expansion tube in interior communication with the outer end of said combustion chamber, said expansion tube serving to direct exhaust gas slugs from a combustion chamber upon the rear of air columns, louvers within the walls of said expansion tube for the admission of air to form said air columns under the negative pressures produced after said exhaust gas slugs have substantially left the area of said louvers in said expansion tubes, said louvers having a corner, a guard vane and an outer vane to prevent the exit of high pressure air from the inside of the expansion tube by an initial Prandtl-Meyer type of expansion around the corner, followed by deflection of the gas flow back into the expansion tube without shock, means for successive charging of said combustion chamber for a sequence of explosions within said chamber to produce a series of slugs of exhaust gases directed down the expansion tube, an electronic pressure-responsive means for successively igniting said charges to produce said slugs, the succession resulting from the explosion of said charges and the passage through the expansion tube giving rise to an inflow of air into the said expansion tubes, a turbine driven by said inflow of air, said turbine rotating said impeller about the center shaft upon which it is mounted.

3. In a pulse jet pump or motor, a casing, a rotary air compressor within said casing, for furnishing compressed air for combustion, said casing constituting a partial air inlet means for said compressor, a high pressure firing chamber adapted to furnish slugs of exhaust gas at high pressure, an expansion tube directly connected to the exhaust end of said firing chamber, said expansion tube having substantially smoothly divergent sides, the larger end thereof being located toward that end of the casing remotest from said compressor, louvers provided with vanes arranged on the sides of said expansion tube to promote inflow of gas thereinto under the suction created by the exit of the exhaust gas slugs therefrom but adapted to substantially prevent outflow of gas through the louvers from said expansion tube, a low pressure air chamber surrounding said expansion tube to constitute a reservoir of air for the supply of said expansion tube, charge-forming means for forming successive charges of an explosion mixture of fuel and air and for introducing them into said high pressure firing chamber, a turbine at substantially that end of the casing which is farthest from the larger end of said expansion tubes, said turbine being driven by the suction created by the flow of air into said expansion tubes and drive means between said turbine and said air compressor whereby to drive said compressor.

4. In a pulse jet pump or motor, a base, a casing mounted thereon, a compressor having a drive shaft, a front bearing for said drive shaft arising from said base, said compressor being revolubly mounted on said shaft whereby to compress air for combustion, a combustion chamber into which said compressor is arranged to discharge, said combustion chamber being adapted to furnish high pressure slugs of gas, said combustion chamber having an open throat for the discharge of the detonated charge of ignition gas, a main charge premixing chamber to mix fuel and air so that detonation can occur in said combustion chamber with efficient combustion, said premixing chamber containing screens for mixing said fuel and air by small scale turbulence, a fuel system, said fuel system being adapted to inject detonatable fuel droplets into said auxiliary premixing chamber, ignition devices to set off an initial detonation in the auxiliary combustion chamber, an expansion tube having substantially smoothly diverging sides to direct slugs of exhaust gas from the main combustion chamber against a column of air whereby to increase the mass of gas and augment the momentum of the gas and air exhausted from said expansion tube, inlet louver vanes to allow air to flow to said expansion tube in the section of high velocity pressure slug of exhaust gas, but to prevent a slug of gas from permanently escaping through the louvers, said louvers and vanes being located at a region of sharply increasing diameter in said expansion tube, the vanes comprising outer vanes to create tangential incidence with the outward expanding gas of the slug and redirect it back into the expansion tubes, guide vanes to reflect expansion waves from the region of suddenly increased diameter to the outer vanes to prevent the formation of shock waves as the peripheral flow of the slug is recompressed and brought into the expansion tube by the outer vanes, a turbine to generate power by the flow of air through said turbine into said expansion tube, and means for driving said compressor from said turbine at an optimum speed for the efficiency of each.

5. A pulse jet pump or motor, a casing for the

partial support of elements contained within said casing, a turbine in said motor driving a rotary compressor at one end of said casing to furnish compressed air for combustion, a fuel supply, a fuel mixing chamber to premix air from said compressor and fuel from said fuel supply, combustion chambers to furnish slugs of high temperature high velocity exhaust gas, a rotary disc inlet valve to periodically admit air for fuel charges to said combustion chambers, a lateral extension for each combustion chamber to provide a narrow cross section suitable for the initiation of a high pressure combustion shock wave, ignition means in said lateral extensions to explode the charge nearly simultaneously throughout the length of the combustion chamber, an expansion tube connected to each combustion chamber to direct slugs of exhaust gas from the combustion chambers against columns of air in the expansion tube to increase the mass and augment the momentum of the discharge from the expansion tube, a plurality of inlet louvers in each expansion tube to promote the ingress of air into the expansion tubes in the wake of successive slugs of exhaust gas and electronic pressure-responsive means to provide means for maintaining a desired expansion tube exhaust pressure by change in the firing frequency.

6. A pulse jet pump or motor comprising a casing for the partial support of internal elements, a turbine in said motor driving a rotary air compressor at one end of said casing to furnish compressed air for combustion, a plurality of combustion chambers positioned to receive air from said compressor, to furnish high pressure high temperature slugs of exhaust gas, inlet valves at the entrance to said combustion chambers to admit periodically an air-fuel mixture to the combustion chambers, said inlet valves comprising rotatable blades alternating with combustion chamber ports, the blades acting periodically to seal the ports while rotating at a high velocity, lateral extensions for the combustion chambers to furnish a priming explosion in each to fire the main charge rapidly in the responsive communicating combustion chamber, igniters in said lateral extensions to fire the entire length of the priming charge in the lateral extensions nearly simultaneously, means for admitting fuel to the main combustion chambers, means for admitting a different fuel to the auxiliary combustion chamber to furnish the priming charge, a plurality of expansion tubes, each expansion tube being in interior communication with a combustion chamber, each expansion tube having smoothly diverging sides and being adapted to discharge in sequence for more nearly constant exit flow of gas from said tubes and casing, each expansion tube having a plurality of cornered louvers to initiate Prandtl-Meyer expansion around the corner at that region of the tube in which supersonic gas flow takes place and to promote the initial part of a gas wake around an obstacle in the sonic portion, vanes to catch the outward flow of gas in slug form tangentially and to lead it back to the main portion of the expansion tube and guides to reflect expansion waves from said corners to the outer vanes to prevent the formation of shock waves, an electronic control for the firing frequency in response to pressure to produce the optimum pressure, said control being responsive to a diaphragm which is located adjacent to the expansion tube so as to be influenced by the exit pressure therein.

7. A pulse jet pump or motor comprising a casing for the partial support of elements within it, an air compressor adapted to furnish compressed air for combustion within said casing, a turbine substantially at one end of said casing drivingly connected to said compressor so as to furnish power thereto by virtue of the air flow caused by the suction of air into said pump or motor, said motor having an air inlet and means adapted to separate air to said turbine and to a low pressure chamber, a fuel inlet means for furnishing and for premixing fuel with air from said compressor to make a combustion charge, turbulence screens for thoroughly mixing of fuel and air by local turbulence created from fuel from said fuel inlet means and compressed air, a plurality of combustion chambers disposed in substantially parallel relation to the longitudinal axis of said case, to furnish slugs of high temperature high pressure exhaust gas, a rotary disc valve adapted to rotate before the inlet portions of said combustion chambers for high frequency charging of said combustion chambers with combustion charges, a plurality of expansion tubes also substantially parallel to the longitudinal axis of the casing, said expansion tubes having sides adapted to increase the internal width of the expansion tubes, at least two sides of each expansion tube having a plurality of successive louvers therein to admit air between successive slugs of gas ejected from said expansion tubes, each louver having a corner, to initiate a Prandtl-Meyer expansion in the supersonic section and to start a wake around an obstacle in the sonic section, vanes in the neighborhood of each louver to catch outward flow resulting from said corners tangentially to redirect it into the expansion tubes with little shock or turbulence, and guides to reflect expansion waves from said corners to the outer vanes whereby to prevent shock waves.

8. In combination in the order named in a pulse jet pump or motor a casing, and within said casing a central shaft, a rotary impeller adapted to compress air mounted on said shaft, a turbine adapted to drive said impeller, a circular air inlet surrounding said impeller and adapted to direct air through said turbine, an air fuel premixing chamber, a plurality of fuel nozzles arranged within said chamber to feed liquid fuel into the air stream from said impeller, a plurality of local-turbulence-inducing screens located across the air flow in said chamber, a rotating drum mounted on said central shaft, a stationary plate at the outer end of the rotating drum, a flexible disc valve at the outer end of said drum, said stationary plate and said disc valve having long narrow ports, adapted to coincide upon revolution of the valve, an outer stationary section comprising a plurality of combustion chambers, fuel jackets surrounding said combustion chambers, to cool the latter, connections between said fuel jackets and said fuel nozzles, an expansion tube projecting from each combustion chamber, each of said expansion tubes being of a generally prismatic shape, louvers and vanes including outer vanes and guard vanes in at least one wall of said expansion tubes whereby to promote an expansion of the Prandtl-Meyer type, and reflect expansion waves to turn the gas flow inward and tangential to the outer vanes, said rotary disc valve and stationary plate ports being aligned with said combustion chambers and adapted to feed intermittently a compressed

mixture of a main fuel and air into said combustion chambers, a lateral extension from each combustion chamber, a series of spark plugs in said lateral extension, a pressure-sensitive pickoff in each of said expansion tubes and an electronic circuit connected to said pickoff and adapted to time the spark at said spark plugs in conformity with pressure conditions existing in said expansion tubes at the point wherein at which said pickoff is located.

9. The combination recited in claim 8 and in addition an air by-pass from said circular air inlet to the louvers and vanes in said expansion tubes.

10. The combination recited in claim 9 and in addition an extensible vane in said air by-pass whereby to regulate the ratio between the volumes of air supplied for driving the turbine with augmentation of mementum of the air flow through the extension tubes and those supplied directly to the premixing and the combustion chambers to form exhaust slugs of gas to impact against the air in the expansion tubes.

11. The combination according to claim 10 in which the turbine is provided with vanes at the periphery thereof, said vanes being angled to drive the turbine by the energy of air sucked against them, said turbine having a perforated disc to allow compressed air from the compressor to pass through the openings therein to the fuel mixing chambers.

12. A pulse jet pump or motor comprising a casing for the partial support of elements within casing, a turbine located substantially at one end of said casing, an air compressing impeller driven by said turbine to furnish compressed air for preparing initial charges of fuel and air, a drive shaft from said turbine, a main premixing fuel chamber positioned to receive fuel from a fuel source and compressed air from said compressor impeller for thoroughly premixing a charge of fuel and compressed air for efficient explosion, said chamber containing parallel fuel pipes in which there are a plurality of substantially regularly spaced ports to spray fuel into the compressed air stream and turbulence inducing screens to promote thorough mixing of said fuel and air by local turbulence, an auxiliary premixing chamber of substantially cylindrical construction concentric to said shaft to mix a detonatable fuel and air, a plurality of combustion chambers to furnish slugs of high temperature high pressure exhaust gas, a lateral extension for each combustion chamber for receiving a detonatable fuel and air charge from said auxiliary premixing chamber, said combustion chambers being adapted to receive fuel and air charges from the main premixing fuel chamber.

13. A pulse jet pump or motor comprising a casing for the partial support of elements within said casing, a turbine located substantially at one end of said casing, an air compressing impeller for said turbine to furnish compressed air for preparing initial charges of fuel and air, a drive shaft from said turbine, a main premixing fuel chamber positioned to receive fuel from a fuel source in compressed form, an impeller for thoroughly premixing a charge of fuel and compressed air for efficient explosion, said chamber containing parallel fuel pipes in which there are a plurality of substantially regularly spaced ports to spray fuel across the compressed air stream, a plurality of baffles supported from the walls of said main premixing chamber to form a labyrinthine path for the flow of the mixing fuel and air, turbulence inducing screens supported partially by said baffles and partially by the walls of said main premixing chamber to provide a multiplicity of localized turbulence inducers across the labyrinthine path, an auxiliary premixing chamber of substantially cylindrical construction concentric to said shaft to mix a detonatable fuel and air, a plurality of combustion chambers adapted to receive charges from the main premixing chamber and to furnish slugs of high temperature high pressure exhaust gas, and a lateral extension for each combustion chamber for receiving a detonatable fuel and air charge from said auxiliary premixing chamber.

14. A pulse jet pump or motor comprising a compressor to furnish a stream of compressed air, a turbine drivingly connected to said compressor, a source of fuel, a premixing fuel chamber to receive air from said compressor and fuel from said fuel source to furnish a mixed fuel and air charge, a combustion chamber for receiving and exploding said fuel and air charge, inlet valves to the said combustion chamber to periodically admit explosive charge, a rotary cushion feed between said premixing fuel chamber and said inlet valves to supply compressed air at the rear of the admitted charges in said combustion chamber before the closing of the inlet valve thereto, to act as a cushion to protect said valve from the high temperature of the explosion, a hollow central shaft upon which said compressor is mounted said shaft being arranged to conduct compressed air from said compressor, said shaft having a multiplicity of transverse openings to allow the entrance of air from said compressor at its exit to the said rotary cushion feed.

15. In combination in an augmented pulse jet pump or motor, an outer casing, a fuel and air charge-preparing section, and a fuel and air charge storage section, a fuel and air charge exploding section and an expansion section for the products of combustion formed in the fuel and air exploding section, said charge forming section including a turbine having peripheral vanes, an air compressing impeller operatively connected to said turbine, an inner casing forward of said turbine, a central shaft upon which said turbine is mounted and to which said impeller is connected a concentric air inlet between said inner casing and said outer casing through which air inlet vanes of said turbine extend, concentric perforated pipes for supplying the main fuel, said pipes mounted ahead of said turbine and said impeller within said inner casing, a central concentric chamber surrounding said shaft, means for admitting compressed air to said chamber, a fuel supply connected to said chamber, a perforated annular pipe for delivering a special fuel into the air stream in said chamber, a deep flange at the outer end of said chamber wall, a baffle mounted on said inner casing between said flange and said impeller, a plurality of annular screens mounted concentrically between said flange and said baffle to provide a labyrinthine path for making said fuel and air charge homogeneous, means in said fuel and air charge compressing section for storing compressed air and fuel preparatory to injecting same into said combustion chambers, a rotary valve having spaced openings, which are aligned between said combustion chambers and said fuel and air storage chambers, a rotary air cushion-feed between said storage chambers and said turbulence-inducing screens for feeding air into said fuel and air storage chambers alternately with the fuel

charges fed therein, a lateral extension for each combustion chamber central continuous passages for feeding a special mixture, fuel and air into said lateral extensions, ignition means mounted in the path of said special fuel and air in said lateral extensions, expansion tubes arranged to receive products of combustion upon firing of said fuel and air charges within said combustion chambers, and means in the sides of said expansion tubes for admitting low pressure air into said tubes behind the combustion gases passing therethrough from a supply of low pressure air surrounding said tubes and contained within said outer casing.

16. The combination set forth in claim 15 having in addition a tube aligned with the shaft, said tube extending through the fuel and air storage section, and mounted concentrically on said tube, a roller hub and an apertured backing plate to preserve the alignment and take the thrust of the rotary valve.

17. The combination set forth in claim 16 having in addition a drum, the rim of which extends from the periphery of the air cushion feed to the periphery of the rotary valve and which rotates with said cushion feed and said rotary valve.

18. The combination set forth in claim 17 in which the relative arrangement of the air cushion feed to the rotary valve is such that the former is blocked when the latter is open and vice-versa.

19. In a pulse jet motor or pump, a charge injection system comprising a substantially cylindrical case, a front tube supported by the casing and fixedly mounted therein, a hollow rear axle supported by the casing and rotatably mounted therein, a drum mounted on and rotatable with said rear axle within said case, and on said front tube a plurality of fixed storage chambers fixedly mounted within said drum, said chambers having front and rear openings radially disposed in respect to said drum, rotary air cushion feeds supporting the rear of said drum from said rear axle, said air cushion feeds being hollow and receiving compressed air from the hollow rear axle, said air cushion feeds having front slits, a rear face plate for the slits in said air cushion feeds to ride over, slots in said face plate leading to said storage chambers, a fixed front plate at the front end of said storage chambers, said plate having radial slots adapted to act as exhausts for said storage chambers, segmental valve blades carried radially by the front of said drum adapted in a plane perpendicular to the drum axis so as to slide over the exhausts in said fixed front plate, radial combustion chamber entrance ducts opposite the exhausts in said fixed front plate to receive the charge from said storage chambers when not blocked by said valve blades between them, said rear stationary plates and rotary air cushion feeds constituting valve means for admitting a fuel-air mixture to the storage chambers when the rotary air cushion feeds do not cover the radial entrance slots in the rear fixed plate, and for admitting cushions of air when said slots are covered by rotary air cushion feeds, said fixed front plate and valve blades at the front of the drum constituting registerable valve means comprising radial slots between segmental blades for permitting the escape of a fuel-air or an air cushion from the storage chambers into the entrances to the combustion chambers just before the valve means at the front of the drum close for firing the combustion chambers, and means comprising flared expansion tubes supported by the said casing in front of said combustion chambers for intermittently creating a decreased pressure to allow entrance into the combustion chambers of a compressed charge of air and fuel followed by a cushion of compressed air, the action of said means being followed by the closing of said valves at the entrance to the combustion chambers and means for causing detonation of said charge in the combustion chambers to repeat the sequence.

20. In combination in the order named in a pulse jet pump or motor a casing, a central shaft supported by the casing and carrying rotary impeller means for compressing air, a turbine driving said shaft, mounted on said shaft, a pair of radially spaced members, one of which is attached to the casing forming an air inlet, an extensible vane supported by the casing and mounted in said inlet, to regulate the fraction of inlet air that passes through said turbine vanes, a plurality of fuel nozzles arranged to feed liquid fuel into the air stream from said impeller, and air fuel premixing chamber in which said fuel jets are located, a plurality of turbulence-inducing screens located across the air flow in said chamber, a rotating drum mounted on said central shaft, a stationary plate at the impeller end of the rotating drum, a plurality of stationary fuel and air mixture storage chambers within said rotating drum, a flexible disc valve at the outer end of said drum, said disc valve having long narrow ports, an outer stationary section comprising a plurality of combustion chambers, fuel jackets surrounding said combustion chambers, an expansion tube projecting from each fuel chamber, each of said expansion tubes being of a generally pyramidal shape, a low pressure air chamber surrounding said tubes, a passage leading from said air inlet to said low pressure air chamber, means in at least one wall of said expansion chamber to maintain a substantially streamline non-turbulent flow in the intermittent passage of compressed gas slugs through the said expansion tubes, and substantially streamline flow from said low-pressure air chambers into the spaces between the gas slugs in said expansion tubes, said rotary disc valve being aligned with said combustion chambers and feeds intermittently upon registration of its openings a compressed mixture of a main fuel and air through the ports into said combustion chambers, a lateral extension from each combustion chamber, a series of spark plugs in said lateral extension, a pressure-sensitive pickoff including a pressure actuated diaphragm in each of said expansion tubes and an electronic circuit timing including a potentiometer controlled by said diaphragm for the spark at said spark plugs in conformity with pressure conditions existing in said expansion tubes at the point wherein at which said pickoff is located and including a servomotor to adjust said extensible vane to apportion air between the driving requirement for said impeller and the supply for said low pressure air chamber.

21. In a pulse jet motor, a compressor, means for driving said compressor, a combustion chamber, passageways for supplying compressed air from the compressor to the combustion chamber, an inlet valve to said combustion chamber, electric ignition means therein, an expansion tube attached to the exhaust end of said combustion chamber, a light source rotary means for interrupting a light beam at a predetermined time after the closing of said inlet valve, a photodetector arranged to receive the interrupted light

beam, an amplifying circuit for the output thereof, a rectifier in said amplifying circuit to allow the passage of a voltage pulse only upon the interruption and not upon the release of said light beam, and thyratron means for producing an ignition pulse on the ignition means in said combustion chamber upon being tripped by a voltage pulse from said photo-detector amplifying circuit.

22. In a pulse jet motor a combustion chamber, means including a compressor for preparing charges therefor, means for driving said compressor an expansion tube attached to the exhaust end of said combustion chamber to receive expanding gases therefrom, electric ignition means in said combustion chamber, a voltage pickoff in said expansion tube, an ignition circuit for automatically changing the speed of a pulse jet motor to operate at the desired pressure in the expansion tube, said ignition circuit including said ignition means, a thyratron, a condenser and said voltage pickoff; a variable-impedance charging circuit for said condenser, a low resistance in said circuit in series with said condenser, a variable impedance tube in series with said charging circuit, a capacity-resistance network across the grid and cathode of said variable impedance tube, a rectifier in series with said voltage pickoff and said capacity-resistance network to bias said variable impedance tube to cut off for a short period following the tripping of the thyratron and the discharge of said condenser thereby allowing said thyratron to open; said low resistance being arranged to permit the condenser to charge up to almost the value of the D. C. voltage source after every discharge so that the voltage pickoff in series with the thyratron will have approximately the same amplitude of voltage pulse across it regardless of change in the firing frequency of the ignition means.

23. In combination in a pulse jet pump or motor a combustion chamber, a rotary valve for admitting a mixture of fuel vapor and air to said combustion chamber, an expansion tube for controlling the expansion of gas from said combustion chamber, an electronic control circuit comprising a shutter in synchronism with said valve, a source of light for said shutter, a photoelectric cell in the path of the light from said light source, a circuit in which said cell is connected for producing an electrical pulse at a sharp decrease of the light impinging upon said photo cell, a trigger circuit connected thereto, electrical trigger means in said circuit responsive to pulse discharge from said first circuit, a spark-gap ignition means actuated by said trigger means, electrical storage means in said trigger circuit, means for re-charging said storage means after every pulse therefrom, pressure sensitive pickoff means in the expansion tube and a circuit for changing the number of operations per second of said spark gap ignition means until the pressure in the expansion tube has dropped or risen below a predetermined value at the point of location of said pickoff.

24. A combination which comprises an augmented-thrust jet pump or motor having combustion chambers and expansion tubes for products of combustion therein, a pressure-sensitive pickoff mounted within at least one of said tubes, electronic means comprising a reference oscillator for establishing reference firing-frequency, a circuit connected to said means, said circuit including means for providing a voltage proportional to the voltage developed by said pickoff in response to the pressure of the products of combustion in the tubes, a pressure-correction circuit adapted to regulate the frequency of said reference oscillator to a value capable of maintaining a firing pressure within said tubes at the desired frequency, a rotary valve for admitting vaporized fuel and air to said combustion chambers, photoelectric means arranged to be cyclically interrupted to said valve to produce firing spark at the closing of said valve at a frequency equal to the desired reference frequency, means for including an extensible vane in the air inlet of said pump or motor and a circuit for comparing the actual speed of firing of the reference frequency and for adjusting said vane in response thereto by the extension or retraction thereof to cause the firing frequency to approach the reference frequency.



25. The combination which comprises an augmented-thrust jet pump or motor having expansion tubes for products of combustion therein, a pressure sensitive pickoff in said tubes, electronic means comprising a reference oscillator for establishing a reference firing frequency, a circuit connected to said means, said circuit including means for providing a voltage proportional to the voltage developed by said pickoff in response to firing pressure, a pressure-correction circuit adapted to regulate the frequency of the reference oscillator to a value capable of maintaining the firing pressure at the desired frequency, a rotary valve for admitting vaporized fuel and air to said expansion tubes, photoelectric means arranged to be cyclically interrupted by said valve for producing a firing spark after the closing of said valve at a frequency equal to the desired firing frequency range, means including an extensible vane in the air inlet of said pump or motor and a circuit for comparing the actual speed of firing and the reference frequency and a servomotor for adjusting said vane to cause the firing frequency to approach the reference frequency and a fuel pump, a variable speed driving motor therefor, and means for regulating the speed of said motor from the said comparison circuit.

26. In a pulse jet pump or motor an air compressor, a turbine arranged to drive said compressor, a combustion chamber, means including a fuel pump for preparing a mixture of vaporized fuel and air, means for storing said mixture, means for intermittently feeding said mixture into said combustion chamber, electrical means for intermittently firing said charges, an expansion tube attached to the exhaust end of said combustion chamber, a circuit including an electric motor connected to said fuel pump for maintaining the speed of the fuel pump proportional to the firing frequency in said combustion chamber, a reference oscillator, an amplifier connected to receive a pulse of the same voltage for every pulse generated by said oscillator, a condenser and a rectifier in series with the output of said amplifier, a direct current generator adapted to furnish a voltage proportional to the speed of the fuel pump motor, a resistance in series with said condenser and generator, the two latter elements connected so as to oppose their voltages, a servomotor controlled by the voltage across said resistance, a variable impedance reactor connected in series with said servomotor to control the current to said fuel pump motor and a mechanical means actuated by said servomotor for controlling the impetance of said reactor.

27. In combination in a pulse jet pump or motor, a compressor, a turbine geared to drive said

compressor, means for forming charges of vaporized fuel and air, combustion chambers for intermittently burning said charges, expansion tubes connected to the exhaust end of each combustion chamber and adapted to receive expanding products of combustion therefrom, a voltage regulator, a pressure sensitive voltage pickoff in each expansion tube, an electronic control circuit responsive to the output voltage of at least one of said pickoffs and said voltage regulator for maintaining a constant predetermined output pressure, said electronic control circuit including an oscillator generating a reference frequency, a reference firing-frequency circuit including said oscillator, a servomotor mechanically connected to said oscillator, a control circuit including said servomotor for varying the oscillator reference frequency in accordance with pressure-correction signals received from said pickoffs, a thyratron, a condenser, a condenser-discharge circuit including said thyratron and said condenser, said circuit being arranged to be tripped by each positive pulse from the output of said oscillator, a direct current voltage circuit for charging said condenser, a variable-impedance tube in series with said charging circuit to confer greatly increased impedance in the charging circuit of said condenser for a short period following the firing of said thyratron, said condenser-discharge circuit and said pickoffs being connnected in series whereby each pulse transmitted through said circuit by the discharge of said condenser, induced by the firing of said thyratron, will have substantially the same voltage.

28. In a pulse jet pump or motor, a compressor, a turbine connected to drive the compressor, a combustion chamber, means for preparing charges of vaporized fuel and air, means for intermittently feeding such charges into said combustion chamber, an expansion tube connected to the exhaust end of said combustion chamber, an electric circuit adapted to indicate a signal representing the difference between the exhaust pressure of said expansion tube in relation to a desired value and to change the operation of the turbine to give the desired exhaust pressure comprising, a pressure pickoff mounted within said expansion tube, a pressure-transmitting tube leading from said pickoff, a pressure box having a central diaphragm in contact with gas from said pressure pickoff tube on one side, a gas at a reference pressure on the other side of said diaphragm, a lever mechanism having one end thereof attached to said diaphragm, a potentiometer having a contactor positioned by the other end of said lever mechanism, said potentiometer having a resistance-taper winding to correct for any non-linearity between the pressure in said expansion tube and the resistance between one end of said potentiometer and the contactor, and leads from one terminal of said potentiometer to give a voltage proportional to the contactor position and hence to the pressure in the expansion tube.

29. In a pulse jet pump or motor, a compressor, a turbine connected to drive the compressor, an air inlet to said turbine and compressor, a combustion chamber, means for preparing a mixture of vaporized fuel and air, means for intermittently injecting charges of said mixture into said combustion chamber, photo-electrical means for measuring the frequency of firing of said charges in said combustion chamber, an expansion tube connected to the exhaust end of said combustion chamber, an electronic circuit maintaining the exhaust pressure of the expansion tube at a desired value by automatically regulating the speed of the turbine when the pressure in the expansion tube deviates from the desired value, said electronic circuit including an electronic circuit adapted to control the fraction of the air for augmenting expansion in said expansion tube which drives the turbine comprising, a first condenser, a first rectifier, a first calibrating resistance, and a first voltage pickoff all connected in series, the pickoff being controlled by the firing frequency measuring means to store a charge proportional to the number of firing voltage pulses per second on said condenser, a reference circuit comprising a second condenser, a second rectifier, a second calibrating resistor, and a second voltage pickoff, one terminal of the same polarity of each condenser being connected together, a first resistance extending across the first condenser, a second resistance extending across the second condenser, an amplifier input connected across the said resistors in series to measure any difference in the voltages of said condensers, and hence any difference in the firing and reference frequencies, a relay connected to the output of said amplifier, a current-reversing circuit actuable by said relay, a servomotor, the current input polarity of which is controlled by said relay and reference circuit, an extensible vane mounted in said air inlet, the degree of extension of which vane determines the amount of air striking the blades of said turbine and therefore determines the turbine and compressor speed and the firing frequency in said combustion chamber, and a mechanical linkage for controlling the position of said vane by said servomotor.

30. In combination with a pulse jet pump or motor having a turbine, a firing chamber having an inlet valve regulated by said turbine, an automatic control system for regulating the speed of said turbine including a photoelectric synchronous firing circuit responsive to the speed of said turbine, said firing circuit comprising, a light source, a rotary shutter in synchronism with said inlet valve for intercepting a beam of light from said source, a photoelectric detector cell toward which said beam of light is directed, an amplifier to which said photoelectric detector cell is coupled, a rectifier coupled between said detector cell and amplifier to produce an electric pulse at a decrease of light impinging upon said detector cell, a firing circuit arranged to receive pulses from said amplifier, a thyratron in said firing circuit adapted to be fired by electrical pulses proceeding from said amplifier, a discharge circuit for said thyratron, a transformer included therein, said transformer having a secondary, a plurality of spark plugs in said firing chamber, said secondary being connected across said plugs, a condenser connected across said thyratron, a normally low series-connected charging resistance for said condenser adapted to obtain the same discharging voltage on said condenser regardless of appreciable variation in charging time for varying frequencies of operation, a pickoff in the discharge circuit of said condenser, a transformer for the pickoff output, means for producing a bias voltage from said pickoff transformer, a variable impedance tube in the charging circuit of said condenser, means for furnishing said voltage to said variable impedance tube, said transformer and said tube being connected in the charging circuit of said thyratron so as to allow said thyratron to reopen

on condenser discharge, and a frequency pulse integrating circuit including a voltage pickoff from said thyratron circuit a rectifier, a condenser, an amplifier and a current source connected thereto.

31. In a pulse jet pump or motor a compressor, a turbine geared to the compressor, a combustion chamber, an expansion tube connected to the output of said combustion chamber, an electronic circuit connecting said expansion tube and said turbine to regulate the speed of said turbine at the desired exhaust pressure in said expansion tube, means connected to said expansion tube for establishing a reference firing frequency, an electronic circuit for correcting said frequency, a differentiating circuit to obtain the magnitude of the rate of change of exhaust pressure of said expansion tube with respect to time for increasing pressure error from the reference value, an amplifying tube therein, a plate circuit for said tube, a variable impedance tube in series with the plate circuit of an amplifying tube of said differentiating circuit to decrease the output of said circuit otherwise giving the magnitude of the time rate of change in exhaust pressure of the expansion tube for decreasing pressure error, a pressure error circuit to buck a voltage proportional to the exhaust pressure of said expansion tube against a reference voltage, a circuit to obtain a voltage proportional to the magnitude of the pressure error voltage but not its sign, a circuit to differentiate the magnitude of the pressure error voltage, a rectifier in series with the output of said circuit for differentiating the pressure error voltage and the grid input of said variable impedance tube in series with the plate circuit of an amplifying tube of the circuit for giving the magnitude of the differential of the time rate of pressure change of the exhaust of said expansion tube, so that said variable impedance tube has a large impedance solely when the polarity of the time rate of change of the magnitude of the pressure error indicates a decreasing pressure error, an amplifier for a correction signal to the reference firing frequency oscillator the input of which is equal to the sum of a voltage proportional to the magnitude of the time rate of change in pressure and the magnitude of the pressure error for increasing pressure errors, but is equal to the sum of a voltage proportional to the magnitude of the pressure error and a voltage less than proportional to the time rate of pressure change for decreasing pressure errors, a second pressure correction signal amplifier whose input is connected to the output of said first correction signal amplifier, a circuit for blanking out the input to said second amplifier when the magnitude of the pressure error is equal to zero, a reversing switch in series with the output of said second amplifier which is actuated by a change in polarity of the pressure error, a second reversing switch in series with the first reversing switch and said reference firing frequency oscillator which is actuated by a change in sign of the rate of change of pressure with frequency independent of the magnitude of this ratio as long as small values of the time rates of change of frequency and pressure occur, a circuit to provide voltage input to an auxiliary coil of said motor for changing the frequency of the reference firing frequency oscillator when the time rate of change of pressure is zero, so that said circuit for actuating the second reversing switch to the frequency adjustment motor of the second oscillator will always have measured time rates of frequency and pressure available to determine the proper position of said second reversing switch, and a circuit to blank out said voltage input to the auxiliary coil of the frequency adjustment motor of the reference firing frequency oscillator throughout the time that a firing frequency drift occurs.

32. An apparatus for the generation of power, comprising a main combustion chamber for a substantially non-detonating fuel-air mixture, an auxiliary combustion chamber connected to the main chamber and provided with means for providing said auxiliary combustion chamber with a readily detonatable fuel-air mixture to act as a primer in detonating the fuel-air mixture in the main combustion chamber, an exhaust throat for the main chamber small with respect to the chamber cross sectional area so that the explosion occurs at nearly constant volume, an expansion tube connected to said exhaust throat to direct the formation and passage of a slug or piston of exhaust gas said expansion tube having openings in the sides thereof to allow air to be drawn into the tube in the wake of the high velocity high pressure slug of exhaust gas and to be exhausted from the expansion tube mouth by the next succeeding slug of exhaust gas, a chamber surrounding the exhaust tube in which a partial vacuum is produced by the suction of air into the exhaust channel between successive slugs of exhaust gas, and a turbine mounted in said chamber and driven by the air passing through said chamber and into the expansion tube said turbine driving a compressor for supplying compressed air to said main combustion chamber.

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