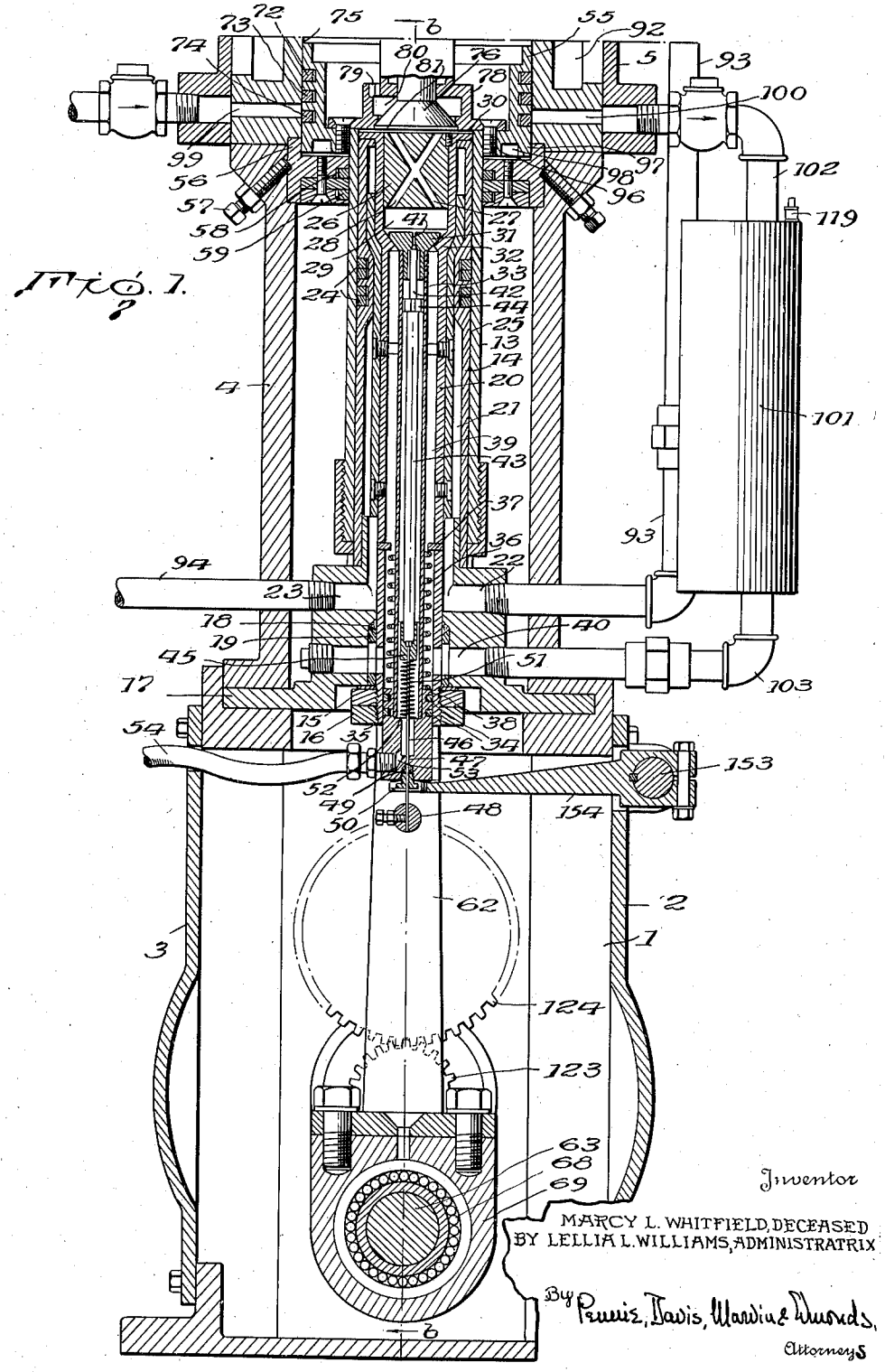
Feb. 18, 1941. M. L. WHITFIELD 2,232,579

INTERNAL COMBUSTION ENGINE

Filed June 21, 1939 4 Sheets-Sheet 1

FIG. 1.



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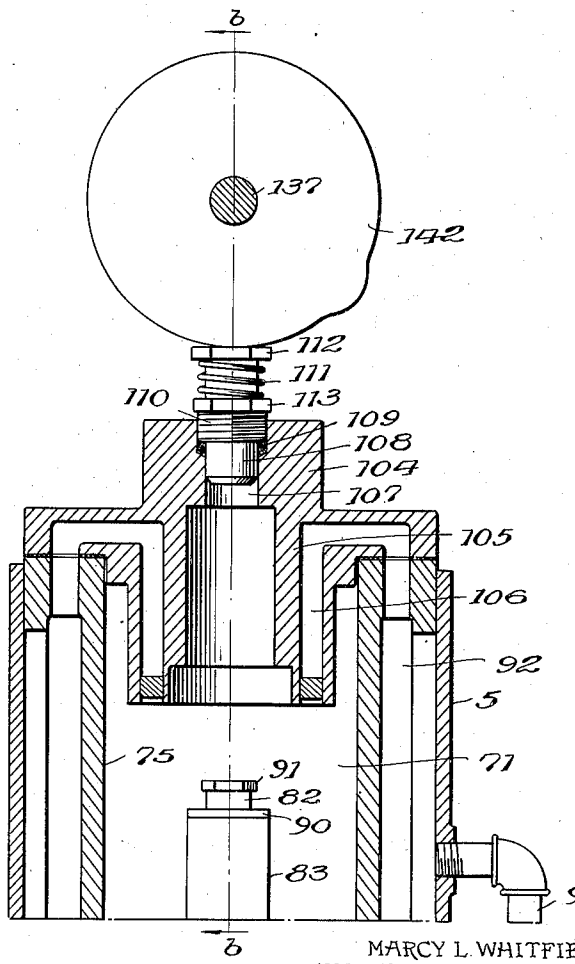
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INTERNAL COMBUSTION ENGINE

Filed June 21, 1939 4 Sheets-Sheet 2

Fig. 7a.



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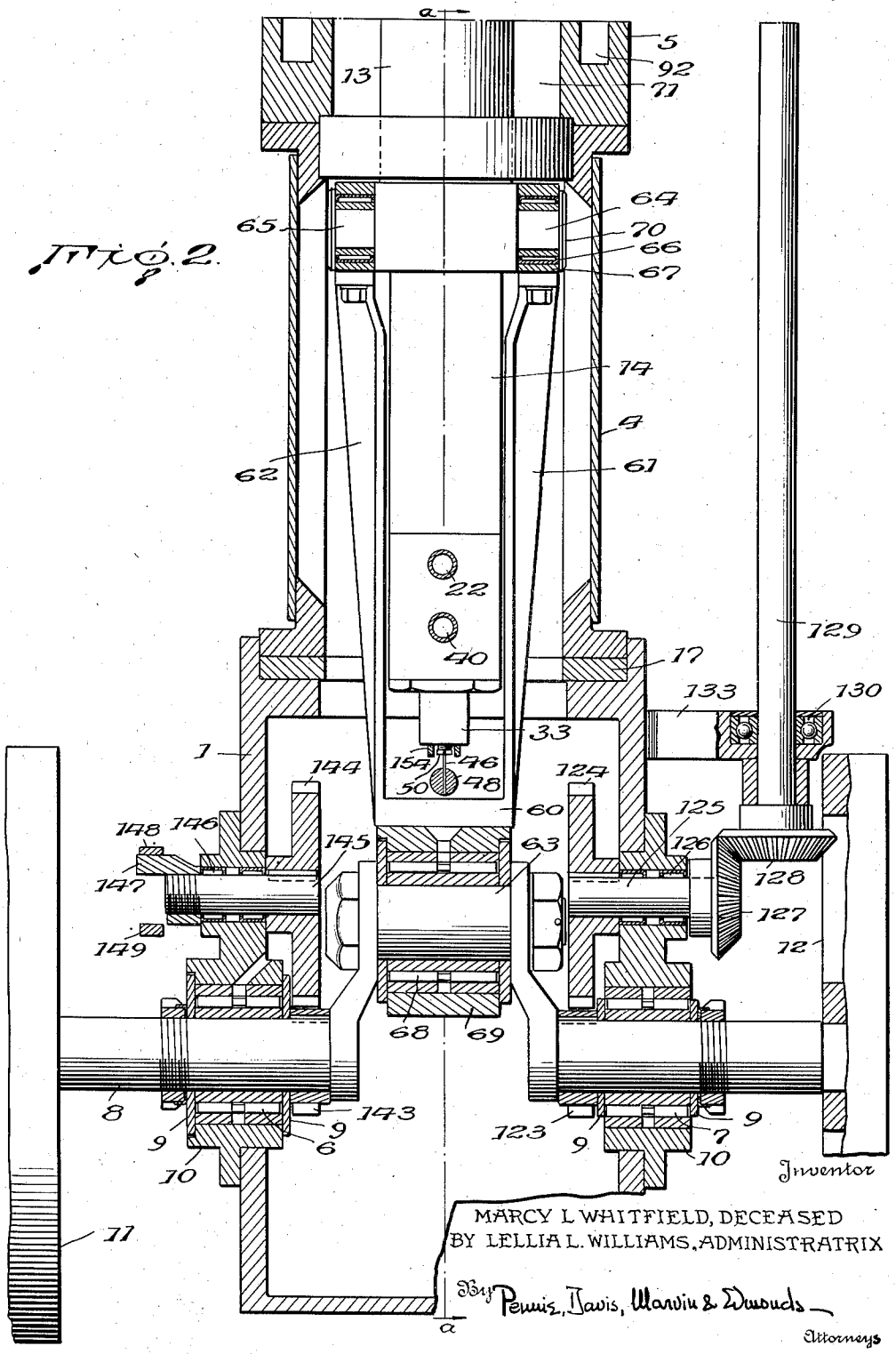
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INTERNAL COMBUSTION ENGINE

Filed June 21, 1939 4 Sheets-Sheet 3

FIG. 2.



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INTERNAL COMBUSTION ENGINE

Filed June 21, 1939 4 Sheets-Sheet 4

Fig. 3.

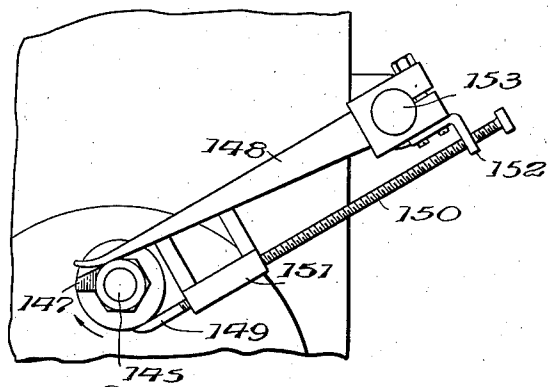
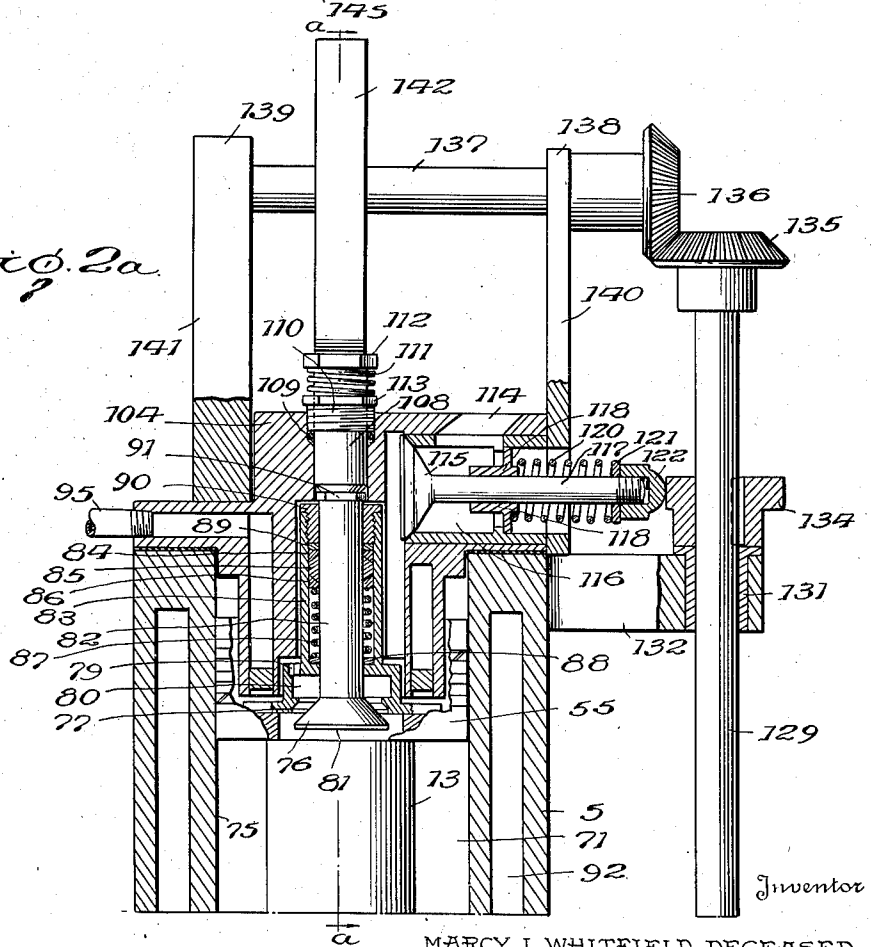


Fig. 2a.



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Patented Feb. 18, 1941

2,232,579

UNITED STATES PATENT OFFICE

2,232,579

INTERNAL COMBUSTION ENGINE

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Application June 21, 1939, Serial No. 280,380

14 Claims. (Cl. 60—15)

This invention relates to an internal combustion engine and to a method of operating same. More particularly the invention relates to an internal combustion engine of the compound type wherein the fuel mixture is introduced into a high-pressure cylinder for combustion, and in which, after combustion, the combustion gases partially expand to perform mechanical work on a member of the high-pressure cylinder, and thereafter are caused to enter into a low-pressure cylinder for further expansion to perform additional work on the piston of the low-pressure cylinder.

According to the present invention, the high-pressure cylinder and the low-pressure cylinder form a unit, any member of which may be used in an engine. The engine is designed to operate as a compound four-stroke cycle engine requiring two revolutions of the crankshaft to complete a cycle, with both power strokes occurring during the second revolution of the cycle. In the preferred embodiment of the invention the engine is made supercharging by drawing air into the low-pressure cylinder during the upward non-power stroke of the engine and compressing and pumping this air out of the low-pressure cylinder on the subsequent downward non-power stroke directly into the high-pressure cylinder or into a chamber connected to the air intake of the high-pressure cylinder. In multiple unit engines the several units may supercharge each other or they may be supercharged from a chamber common to the several units.

Also according to the present invention, the high-pressure cylinder and the low-pressure cylinder are so associated and connected that loss of heat during the transfer of the partially expanded products of combustion from the high-pressure cylinder to the low-pressure cylinder is reduced to a minimum, thereby increasing the efficiency of the engine.

In accordance with the present invention a movable high-pressure cylinder is reciprocable about a stationary cylinder head and is unitary with the piston of the low-pressure cylinder to reciprocate therewith. The piston of the low-pressure cylinder preferably includes the valve mechanism which operates the high-pressure exhaust valve which controls the passage of gases from the high-pressure cylinder to the low-pressure cylinder, and since the engine operates on a four-stroke cycle, the high-pressure exhaust valve opens only on every other revolution. The opening of the exhaust valve is controlled by a tappet, operated by a cam mounted on a cam shaft, and of sufficient rigidity to open the high-pressure exhaust valve against the pressure in the high-pressure cylinder at the end of the upward power stroke.

The high-pressure exhaust valve mechanism which controls the passage of gases from the high-pressure cylinder to the low-pressure cylinder is of novel construction and is adapted to overcome the objections to the operation of exhaust valves which are closed by the impact of the valve face against a stationary member of the engine with resultant rapid deterioration of the valve seat and the imposing of considerable stresses on the valve members. The shock of impact of the valve face against a stationary member of the engine is taken up by a braking element which prevents the valve from hitting the valve seat, and frictionally retains the valve stem in any position to which it is moved. Thus, at the end of the upward power stroke, the tappet pushes the valve stem downwardly against the effort of the braking element and the latter holds the stem in this downward position. As this piston moves downwardly on the next downward power stroke, although the tappet no longer engages the stem, the latter is kept from moving upwardly to its original position by the braking element thereby maintaining the high-pressure exhaust valve open. At the end of the downward power stroke, the impact of the valve face against the stationary high-pressure cylinder head pushes the valve stem inwardly against the effort of the brake element and since at the end of the downward stroke the valve seat of the high-pressure exhaust valve is spaced however slightly from the surface of the stationary high-pressure cylinder head, the valve will close to within a small distance of its seat. Thus, the entire impact will be taken up by the brake element and the valve seat will be spared the high velocity impact of the valve itself. The final seating of the valve takes place on the next downward stroke under pressure of supercharging air in the high-pressure cylinder, the small leakage around the periphery of the valve being insufficient to prevent seating of the valve by low-pressure air, if the brake element is properly adjusted.

Also, according to the invention, the engine is provided with a fuel and air feeding mechanism of novel construction.

The preferred embodiment of the invention is shown in the accompanying drawings and will be hereinafter described in detail. However, it is to be understood that the invention is not limited to the precise construction and arrangement shown,

as modifications and changes are contemplated and such must be considered to be included within the scope of the claims.

In the drawings:

Fig. 1 and Fig. 1ª represent a vertical section view of an engine embodying the invention, said view being taken on line *a*—*a* of Figs. 2 and 2ª but with the crankshaft at low dead center.

Fig. 2 and Fig. 2ª are a vertical section view taken on line *b*—*b* of Figs. 1 and 1ª but with the crankshaft at top dead center.

Fig. 3 is a view showing a part of mechanism for actuating the air and fuel valves.

Preferably, and as shown in the drawings, the engine comprises a crank case or base 1 provided with cover plates 2 and 3 and supporting a high-pressure cylinder housing 4 and a low-pressure cylinder 5. The crank case is provided with bearings 6 and 7 for supporting a crankshaft 8 and these bearings comprise plates 9 which are spaced by a bearing housing 10. Outside the crank case, the crankshaft carries two fly wheels 11 and 12.

The high-pressure cylinder 13 is movable and reciprocates about a stationary cylinder head 14. A stationary guide member 20 is rigidly mounted by lock nuts 15 and 16 within a bore of a lintel member 17 transversely bridging an opening in the crank case. The space between the bore of the lintel member 17 and the surface of the stationary cylinder head 14 is filled with packing 18 held in place by a packing gland 19.

The stationary cylinder head 14 about which the high-pressure cylinder 13 is guided for reciprocation includes the air and fuel pipes, the air and fuel valves, and the stems for operating these valves. Accordingly, the stationary cylinder head 14 comprises stationary tubular member 20 having spaced walls to provide an annular water jacket 21, ports 22 and 23 providing for entrance and exit respectively of circulating water to and from the annular space 21. The upper, outer surface of the stationary tubular member 14 is provided with expansible packing rings 24 which engage the bore 25 of the high-pressure cylinder 13.

Turbulence of the fuel-air mixture prior to and during firing, is obtained through a turbulator 26 mounted at the upper or cylinder head end of the tubular member 20 and consisting of a metal block provided with transverse ports 27 and 28 connecting the space 29 within the tubular member 20, where air and fuel intermingle, with the space 30 in the high-pressure cylinder 13.

Air is fed into the chamber 29 through the opening of a poppet valve 31 normally seated on a valve seat 32 integral with the inner surface of the tubular member 20. The poppet valve 31 is actuated through a tubular valve stem 33 adapted to reciprocate within the stationary tubular member 20 and for this purpose, the lower surface of the tubular valve stem 33 is provided with expansible packing rings 34 which engage the surface of the bore 35 in the tubular member 20.

The lower end of the tubular valve stem 33 projects through the bore 35 and is engaged by the air-valve actuating mechanism which will be described later.

To maintain the poppet valve 31 normally seated, a spring 36 is interposed between an annular projection 37 on the lower inner surface of tubular member 20 and a shoulder 38 on the lower outer surface of the tubular valve stem 33. Air is introduced into the annular space 39 between the inner surface of the stationary tubular member 20 and the outer surface of the tubular valve stem 33 through a port 40 in the lower end of the stationary tubular member 20.

Fuel is injected into chamber 29 through a port 41 centrally located in the face of the poppet valve 31. The port 41 connects the space within the tubular stem 33 or the fuel pipe, with chamber 29 and the passage of fuel therethrough is controlled by a valve 42 normally seated on the tapered lower surface of the port 41. The valve 42 is operated through a rod 43 adapted to be reciprocated and provided with guide means 44 for maintaining it in its path of movement. A fuel valve head 45 is mounted on the lower end of the rod 43 from which another rod 46 extends downwardly, through and beyond a centrally located bore 47 in the closed lower end of the tubular valve stem 33. A ball 48 is rigidly mounted at the extremity of rod 46 and the ball 48 and the rod 46 are engaged by a fuel-valve operating mechanism which will be described later.

The space between the rod 46 and the surface of the bore 47 is filled with packing 49 to insure against leaks, and the packing is kept in place by a packing gland 50.

To maintain the valve 42 normally seated, a spring 51 is interposed between the valve head 45 and a shoulder 52, extending inwardly from the inner surface of the tubular valve stem 33. Fuel is introduced into the tubular valve stem 33 through a port 53 in the lower end of the tubular valve stem 33. Fuel is conducted to the port 53 through a flexible fuel line 54 to permit reciprocation of tubular valve stem 33.

The high-pressure cylinder 13 is unitary with the piston 55 of the low-pressure cylinder 5 to reciprocate therewith and includes the tubular member 13 projecting downwardly from the lower surface of the piston 55. As the products of combustion expand only to a limited extent in the high-pressure cylinder, that cylinder is of less volume than the low-pressure cylinder and preferably has a diameter smaller than the low-pressure cylinder 5. The high-pressure cylinder 13 reciprocates within a bore in a housing 56, held in place at the top of the high-pressure cylinder housing 4 by set screws 57. The housing 56 is provided with expansible packing rings 58 and 59 which embrace the outer surface of high-pressure cylinder 13 and prevent leakage of gases from the low-pressure cylinder 5 into the housing 4 of the high-pressure cylinder.

Reciprocation of the high-pressure cylinder 13 and of the piston 55 of the low-pressure cylinder 5 imparts rotary motion to the crankshaft 8 through a forked connecting rod 60 having arms 61 and 62 straddling the lintel member 17. The connecting rod 60 connects the high-pressure cylinder 13 with a crank pin 63 of the crankshaft 8 through a cross-head consisting of a pair of diametrically opposed wrist pins 64 and 65 mounted on the outer surface of the high-pressure cylinder 13. Each arm of connecting rod 60 connects one of the wrist pins with the crank pin 63 of the crankshaft 8 through a bearing 66 held in a suitable bearing housing 67 and a bearing 68 supported by a bearing block 69. Each arm of the connecting rod is kept in place on a wrist pin by a pin cap 70. The piston of the low-pressure cylinder reciprocates through the space 71 of the low-pressure cylinder 5 and is provided with expansible packing rings 72, 73 and 74 engaging inner surface 75 of low-pressure cylinder 5 to prevent leakage of gases from the

expansion end of the low-pressure cylinder into the compression end of the low-pressure cylinder.

The high-pressure exhaust valve which controls the passage of gases from the high-pressure cylinder 13 into the low-pressure cylinder and the braking mechanism for the high-pressure exhaust valve are mounted on the piston 55 of the low-pressure cylinder 5. In the preferred design, the high-pressure exhaust valve is a poppet valve 76 with a valve seat 77 at the lower edge of a valve cage 78 centrally located in and unitary with the piston 55. The valve cage 78 is provided with a port 79 connecting a chamber 80 of the valve cage 78 with the space 71 of the low-pressure cylinder 5, thus when the poppet valve 76 is unseated at the end of an upward power stroke, gases from the high-pressure cylinder 13 will pass into the chamber 80 and thence through the port 79 into the low-pressure cylinder 5. According to the invention, the lower surface of the valve cage 78 is positioned above the lower surface of the piston 55, a distance such that at the end of a downward stroke of the piston, if the poppet valve 76 is fully seated, the surface 81 of the valve 76 will not come in contact with the upper surface of the turbulator 26 but will leave a small space 30 of about three-sixty fourths of an inch, between the surface 81 of the valve 76 and the upper surface of the turbulator 26. The poppet valve 76 is actuated through a valve stem 82 which projects upwardly through an opening in the upper surface of the cage 78 and through a bore in the crown 83 which is unitary with and is centrally located on the cage 78. The braking mechanism of the high-pressure exhaust valve is mounted within the bore of the crown 83 and consists of an annular friction member split into three parts 84, 85 and 86, the angularity of the three parts cooperating under the effort of a spring 87 to cause the friction member to engage the valve stem 82. Washers 88 and 89 are placed below the spring 87 and on top of the split friction member, respectively, and the whole is kept in place by a tension screw 90 screwed into the bore of the crown 83.

The stem of a high-pressure exhaust valve 76 projects slightly beyond the bore in the crown 83 and its flat upper surface 91 is adapted to be operatively engaged by a tappet mechanism, to be described later, at the end of an upward power stroke.

The low-pressure cylinder 5 has spaced walls to provide an annular water jacket 92 which is connected through suitable piping 93 to the water jacket 21 of the stationary cylinder head 14. Water circulates from the jacket surrounding the low-pressure cylinder to the jacket surrounding the stationary cylinder head and then to a heat exchanger (not shown) through piping 94 and then back to the low-pressure cylinder jacket at 95. Due to cleats or spleens 20' screwed or otherwise secured to the tubular member 20 the water entering the water jacket 21 from the pipe 93 is caused to flow upwardly along one side of the stationary tubular member 14, around the upper portion of the tubular member 20 which encloses the turbulator 26, and then downwardly along the opposite side of the stationary tubular member 14, before passing through the outlet 23 into the pipe 94.

To provide for a supercharging air compressor displacement space when the piston 55 is at the end of a downward non-power stroke, the lower surface of the piston 55 is provided with two concentric annular projections 96 and 97 to form an annular space 98 with the upper surface of the housing 56.

Supercharging air is drawn into the low-pressure cylinder 5 through a port 99 at the compression end of the low-pressure cylinder 5 during an upward non-power stroke of the piston 55, and on a subsequent downward non-power stroke of the engine the piston 55 acts as a compressor for the supercharging air and forces the air out of the low-pressure cylinder 5 through a port 100 at the compression end of the low-pressure cylinder into a chamber 101 provided with a relief valve 119 to relieve against excessive pressure. The compressed air chamber 101 is connected with the port 100 through suitable piping 102 and is also connected through suitable piping 103 with the air-intake port 40 in the stationary tubular member 20. The chamber 101 is desirable only in single unit engines.

The head 104 of the low-pressure cylinder 5 is provided with a centrally located annular projection 105 adapted to embrace the crown 83 of the piston 55 when the latter is at the end of an upward stroke. The annular projection 105 is also provided with a water jacket 106 communicating with the water jacket 92 of the low-pressure cylinder 5.

The tappet mechanism which engages the stem of the high-pressure exhaust valve to actuate the same is mounted in a bore 107 centrally located in the head 104 of the low-pressure cylinder and consequently centrally located with respect to the annular projection 105. A tappet 108 is slidably mounted within the bore, and the upper portion of the latter has a diameter larger than the lower portion to provide for a packing 109 which is kept in place by a suitable packing gland 110. To maintain the tappet 108 normally out of engagement with the stem 82 of the high-pressure exhaust valve, an extension spring 111 is interposed between a crown 112 on the tappet 108 and a crown 113 on the packing gland 110.

Following a downward power stroke, the expansion space 71 of the low-pressure cylinder 5 will be filled with waste gases which must be removed on the subsequent upward non-power stroke of the piston 55. To permit the exhaust of such waste gases, the casing of the low-pressure cylinder 5 is provided with a port 114, and passage of gases therethrough is controlled by a low-pressure exhaust valve, preferably in the form of a poppet valve 115 normally seated on the inner end of a bore 116 in the casing of the low-pressure cylinder 5. The stem 117 of the poppet valve 115 projects horizontally through a bushing 118 mounted on the bore 116 outside of the low-pressure cylinder casing, where it is engaged by an actuating mechanism which will be described later. To maintain the low-pressure exhaust valve 115 normally seated, an extension spring 120 is interposed between the bushing 118 and a washer 121 kept in place by a cap nut 122 screwed onto the extremity of the stem 117, and having a hemispherical surface to be engaged by a cam to actuate the low-pressure exhaust valve.

In order that the operation of the high-pressure exhaust valve 76, the low-pressure exhaust valve 115, the air-valve 31, and the fuel-valve 42, shall be timed properly with respect to the speed of the engine so that actuation of these valves will take place at the proper instant in the operating cycle of the engine, the crankshaft 8, inside of the crank case of the engine, is provided with a gear 123 meshing with another gear 124 mounted at one end of a shaft 125 sup-

ported in the bearings 126 held in a suitable port in the crank case. The size of the gears 123 and 124 is such that a 2:1 speed reduction is obtained. A bevel gear 127 is mounted at the other end of the shaft 125, outside the crank case, and engages a companion bevel gear 128 having the same number of teeth, and mounted at the lowest extremity of a vertical timing shaft 129, held in suitable bearings 130 and 131 supported by arms 132 and 133 projecting laterally from the low-pressure cylinder casing and from the crank case, respectively.

The low-pressure exhaust valve 115 is actuated by a cam 134 mounted on the vertical timing shaft 129 and engaging the hemispherical surface of the cap nut 122 at the extremity of the stem 117 of the valve 115. Since the vertical timing shaft 129 is rotating at one half the engine speed, the low-pressure exhaust valve 115 will open once in two revolutions of the crankshaft.

To actuate the tappet controlling the operation of the high-pressure exhaust valve 76, the vertical timing shaft 129 is provided with another bevel gear 135 adapted to engage a companion bevel gear 136 having the same number of teeth and mounted on a horizontal timing shaft 137 supported in suitable bearings 138 and 139 held in brackets 140 and 141 projecting upwardly from the head 104 of the low-pressure cylinder 5. The tappet 108 is actuated by a cam 142 mounted on the horizontal timing shaft 137, and since the latter is rotating at one half the engine speed, the tappet 108 will open the high-pressure exhaust valve 76 once in two revolutions of the crankshaft.

The operation of the high-pressure exhaust valve and of the low-pressure exhaust valve is synchronized with the operating cycle of the engine by the proper positioning of the cam 134 on the vertical timing shaft 129, and of the cam 142 on the horizontal timing shaft 137.

To actuate the air-valve and fuel-valve, the crankshaft 8 is provided with a gear 143 meshing with another gear 144 mounted at one end of a shaft 145, supported in a bearing 146 held in a suitable port in the crank case. As in the case of the gears for driving the timing shafts, the size of the gears 143 and 144 is such that a 2:1 speed reduction is likewise obtained. A cam 147 is mounted at the other end of the shaft 145, outside the crank case, and is adapted to rotate between the extremities of two substantially parallel rocker arms 148 and 149. The portion of the rocker arm 148 engageable by the cam 147 is fixed in length so that for a given speed of rotation of the cam 147, the rocker arm 148 will be subjected to upward motion during a given period of time, whereby the time of contact between the cam and the rocker arm will be constant. The portion of the rocker arm 149 engageable by the cam 147 may be varied in length so that for a given speed of rotation of the cam 147, the rocker arm 149 will be subjected to downward motion for a variable period of time. To that end, the rocker arm 149 consists of a rod 150 threaded through openings in the guide members 151 and 152 rigidly mounted on the arm 148. The portion of the rocker arm 149 engageable by the cam 147 may be manually adjusted or varied through a governor mechanism (not shown) driven in any suitable manner from the crankshaft.

The other extremity of the rocker arm 148 is rigidly mounted at one extremity of a horizontal rocker shaft 153 supported in suitable bearings on the crank case. Another rocker arm 154 is rigidly mounted at the other extremity of the horizontal rocker shaft 153 so that rocking motion imparted to the rocker shaft 153 by the rocker arms 148 and 149 will be imparted to the rocker arm 154. The extremity of the rocker arm 154 away from the rocker shaft 153 is forked and straddles the rod 46 of the fuel valve 42 above the ball 48, and below the closed end of the tubular stem of the air-valve 31. When the rocker arm 154 is moved upwardly its upper surface will engage the stem of the air-valve 31, will move it upwardly against the action of the spring 36 and open the air-valve 31; when the rocker arm 154 is moved downwardly, the forked ends will engage the ball 48 and pull the rod 46 downwardly against action of the spring 51 to open the fuel-valve 42. Thus, downward movement of the rocker arm 154 controls the injection of fuel, and upward movement of the rocker arm 154 controls the injection of air. Since for a given engine speed, the duration of downward movement of the rocker arm 154 may be varied, the quantity of fuel injected may be varied while the quantity of air fed to the engine remains constant.

The operation of the air-valve and of the fuel-valve likewise is synchronized with the operating cycle of the engine by the proper positioning of the cam 147 on the shaft 145.

The engine may be started by air or steam pressure or by other starting means.

In starting, during the upward non-power stroke of the piston 55, air is drawn into the low-pressure cylinder through the port 99, and during the subsequent downward non-power stroke of the piston 55, air is compressed below the piston 55 and is pumped out of the low-pressure cylinder 5 through the port 100 into the compressed air chamber 101. Also, during the upward non-power stroke, the air-valve 31 opens and the high-pressure cylinder 13 is filled with air which is compressed into the combustion chamber in the stationary cylinder head 14, during the subsequent downward non-power stroke. At the end of this stroke, fuel is injected through the port 41 and is thoroughly commingled with compressed air in the high-pressure cylinder 13 where it will burn quickly and completely. Combustion will push the piston 55 upwardly and at the end of the upward power stroke, the tappet 108 engages the stem 82 of the high-pressure exhaust valve 76 and moves it inwardly against the brake mechanism which will hold the valve stem 82, thereby maintaining the high-pressure exhaust valve 76 open. Thus, the products of combustion will pass from the high-pressure cylinder 13 into the upper or expansion end of the low-pressure cylinder 5, so that the piston 55 therein will move downwardly and perform a downward power stroke.

During the downward power stroke, the products of combustion still remaining in the high-pressure cylinder 13 will be pumped out through the high-pressure exhaust valve 76 kept open by the braking element, and at the end of the downward power stroke the impact of the fact 81 of the high-pressure exhaust valve 76 against the turbulator 26 will cause the valve stem 82 to move upwardly against the brake mechanism to close the high-pressure exhaust valve 76 to within about three sixty-fourths of an inch of its seat. At the end of the downward power stroke, the low-pressure exhaust valve 115 opens and the cycle is repeated. Thus, during the fol-

lowing upward non-power stroke the piston 55 scavenges the expansion chamber 71 of the low-pressure cylinder 5, the waste gases leaving through the port 114, the air-valve 31 opens and air enters into the high-pressure cylinder, and on the next downward non-power stroke the piston 55 will compress the air in the high-pressure cylinder to an extent that will be sufficient to finally seat the high-pressure exhaust valve 76 at the end of the downward non-power stroke. From the foregoing, it will appear that the downward non-power stroke and the upward power stroke of the piston 55 are idle strokes in so far as the space in the expansion chamber 71 of the low-pressure cylinder 5 is concerned.

Thus, the engine operates as a supercharging engine requiring two revolutions of the crankshaft of the engine and four strokes to complete a cycle, with two non-power strokes immediately following each other during the first revoluiton of the cycle and two power strokes immediately following each other during the second revolution of the cycle.

What is claimed is:

1. An internal combustion engine comprising a stationary cylinder head, a high-pressure combustion cylinder reciprocable about said stationary cylinder head into which constituents of a combustible mixture are introduced and in which ignition takes place and the products of combustion partially expand, a low-pressure cylinder in tandem relation with respect to said high-pressure cylinder in which further expansion of the products of combustion takes place, a piston reciprocable in said low-pressure cylinder having a port through which the gases from the high-pressure combustion cylinder enter the low-pressure cylinder for further expansion, and means for controlling the passage of gases through said port, said controlling means comprising a valve mechanism including a valve adapted to close said port, a stem for said valve and a part adapted to engage said stationary cylinder head, means engageable with the valve stem to move the same relative to the piston, the part of said valve mechanism which is adapted to engage said stationary cylinder head, when the valve is open and the piston approaches said stationary cylinder head, impinging against said stationary cylinder head and causing the valve to be moved to a partially closed position, said valve being moved to its completely closed position by the forces exerted by the compression of gases in the high-pressure cylinder, the relative position of said stationary cylinder head to said piston, when said piston is in its extreme inward position, being such that said part of the valve mechanism which is adapted to engage said stationary cylinder head will not impinge thereagainst when the valve is in its completely closed position, and braking means engaging said valve stem and exerting a frictional force thereon to retain said stem in any position as long as the force tending to move the valve stem relative to the piston is less than the retaining force of the braking means.

2. An internal combustion engine comprising a stationary cylinder head, a high-pressure combustion cylinder reciprocable about said stationary cylinder head into which constituents of a combustible mixture are introduced and in which ignition takes place and the products of combustion partially expand, a stationary low-pressure cylinder arranged in substantially axial alignment with said high-pressure cylinder in which further expansion of the products of combustion takes place, a piston reciprocable in said low-pressure cylinder and unitary with said high-pressure cylinder to reciprocate therewith, said piston having a port through which the gases from the high-pressure combustion cylinder enter the low-pressure cylinder for further expansion, and means for controlling the passage of gases through said port, said controlling means comprising a valve mechanism including a valve adapted to close the port having a valve head adapted to engage said stationary cylinder head, and a stem for said valve, means engageable with the valve stem to move the same relative to the piston, the valve head, when the valve is open and the piston approaches said stationary cylinder head, impinging against said stationary cylinder head and causing the valve to be moved to a partially closed position, said valve being moved to its completely closed position by the forces exerted by the compression of gases in the high-pressure cylinder, the relative position of said stationary cylinder head to said piston, when said piston is in its extreme inward position, being such that said valve head will not impinge thereagainst when the valve is in its completely closed position, and braking means engaging said valve stem and exerting a frictional force thereon to retain said stem in any position so long as the force tending to move the valve stem relative to the piston is less than the retaining force of the braking means.

3. An internal combustion engine comprising a stationary cylinder head, a high-pressure cylinder reciprocable about said stationary cylinder head and forming with said stationary cylinder head a combustion chamber into which compressed air and fuel are introduced to form a combustible mixture and in which ignition of the mixture takes place and the products of combustion partially expand, a low-pressure cylinder in which further expansion of the products of combustion takes place, said low-pressure cylinder having inlet and outlet ports through which air enters and leaves respectively, a piston reciprocable in said low-pressure cylinder, air-inlet means in said stationary cylinder head, and means connecting the outlet port of the low-pressure cylinder with said air-inlet means of the stationary cylinder head, whereby air entering the low-pressure cylinder will be compressed and pumped out of said low-pressure cylinder by the piston therein on its compression stroke for introduction into said air-inlet means of the stationary cylinder head.

4. An internal combustion engine comprising a stationary cylinder head, a high-pressure cylinder reciprocable about said stationary cylinder head and forming with said stationary cylinder head a combustion chamber into which compressed air and fuel are introduced to form a combustible mixture and in which ignition of the mixture takes place and the products of combustion partially expand, a low-pressure cylinder in which further expansion of the products of combustion takes place, said low-pressure cylinder having at its compression end inlet and outlet ports through which air enters and leaves respectively, a piston reciprocable in said low-pressure cylinder, air-inlet means in said stationary cylinder head, and means connecting the outlet port of the low-pressure cylinder with said air-inlet means of the stationary cylinder head including a chamber having a pressure-relief valve, whereby air entering the low-pressure cylinder will be compressed and pumped out of said low-

pressure cylinder by the low-pressure cylinder piston on its compression stroke for introduction into said air-inlet means for the high-pressure cylinder.

5. An internal combustion engine comprising a stationary cylinder head, a cylinder reciprocable about said stationary cylinder head and with said stationary cylinder head forming a combustion chamber, said stationary cylinder head including an outer tubular member, an inner tubular member substantially coaxially positioned within said outer tubular member, means for passing a constituent of a combustible mixture through said outer tubular member and about said inner tubular member into said combustion chamber, means for passing another constituent of the combustible mixture through said inner tubular member into said combustion chamber, means for controlling the passage of the constituent of the combustible mixture through said outer tubular member, means for controlling the passage of the other constituent of the combustible mixture through said inner tubular member, and means constantly tending to maintain the passage through said tubular members closed.

6. An internal combustion engine comprising a stationary cylinder head, a cylinder reciprocable about said stationary cylinder head and with said stationary cylinder head forming a combustion chamber, said stationary cylinder head including an outer tubular member, an inner tubular member substantially coaxially positioned within said outer tubular member, means for passing a constituent of a combustible mixture through said outer tubular member and about said inner tubular member into said combustion chamber, means for passing another constituent of the combustible mixture through said inner tubular member into said combustion chamber, means for imparting turbulence to the combustible mixture, means for controlling the passage of the constituent of the combustible mixture through said outer tubular member, means for controlling the passage of the other constituent of the combustible mixture through said inner tubular member, and means constantly tending to maintain the passage through said tubular members closed.

7. An internal combustion engine comprising a stationary cylinder head, a cylinder reciprocable about said stationary cylinder head and with said stationary cylinder head forming a combustion chamber, said stationary cylinder head including an outer tubular member, an inner tubular member substantially coaxially positioned within said outer tubular member, means for passing air through said outer tubular member and about said inner tubular member into said combustion chamber, means for passing fuel through said inner tubular member into said combustion chamber, a valve for controlling the passage of the air through said outer tubular member, said inner tubular member being the stem of said air-valve and being slidably mounted within said outer tubular member to operate said air-valve, said air-valve having a port for the passage of fuel from said inner tubular member to said combustion chamber, a valve to open and close said port, a rod slidably mounted within said inner tubular member to operate said fuel valve, and springs cooperating with said inner tubular member and with said rod constantly tending to maintain said air-valve and said fuel-valve seated.

8. An internal combustion engine comprising a stationary cylinder head, a cylinder reciprocable about said stationary cylinder head and with said stationary cylinder head forming a combustion chamber, said stationary cylinder head including an outer tubular member, an inner tubular member substantially coaxially positioned within said outer tubular member, means for passing air through said outer tubular member and about said inner tubular member into said combustion chamber, means for passing fuel through said inner tubular member into said combustion chamber, means for imparting turbulence to the combustible mixture, a valve for controlling the passage of the air through said outer tubular member, said inner tubular member being the stem of said air-valve and being slidably mounted within said outer tubular member to operate said air-valve, said air-valve having a port for the passage of fuel from said inner tubular member to said combustion chamber, a valve to open and close said port, a rod slidably mounted within said inner tubular member to operate said fuel valve, and springs cooperating with said inner tubular member and with said rod constantly tending to maintain said air-valve and said fuel-valve seated.

9. In an internal combustion engine in which the air is compressed in the combustion chamber thereof and the fuel thereafter is injected into the compressed air and in which the introduction of the air and of the fuel into the combustion chamber is controlled by separate, substantially coaxially positioned valves; the improvement which comprises means for operating said valves including a cam, a shaft, an arm rigidly mounted on said shaft and operatively engaged by said cam to swing said arm in one direction, means mounted on said arm and cooperating with said cam to swing said arm in the opposite direction, so that upon rotation of said cam, an oscillatory motion will be imparted to the shaft, and a second arm rigidly mounted on the shaft and adapted to engage the air-valve-operating means and the fuel-valve-operating means, whereby the oscillatory motion of the shaft is imparted to said second arm to actuate the air-valve-operating means and the fuel-valve-operating means.

10. In an internal combustion engine in which air is compressed in the combustion chamber thereof and the fuel thereafter is injected into the compressed air and in which the introduction of the air and fuel to the combustion chamber is controlled by separate valves; the improvement which comprises means for operating said valves including a cam, a shaft, an arm rigidly mounted on said shaft and operatively engaged by said cam to swing said arm in one direction, means mounted on said arm and cooperating with said cam to swing said arm in the opposite direction, so that upon rotation of said cam, an oscillatory motion will be imparted to the shaft, and a second arm rigidly mounted on the shaft and adapted to engage the air-valve-operating means and the fuel-valve-operating means, whereby the oscillatory motion of the shaft is imparted to said second arm to actuate the air-valve-operating means and the fuel-valve-operating means.

11. In an internal combustion engine in which air is compressed in the combustion chamber thereof and the fuel thereafter is injected into the compressed air and in which the introduction of the air and fuel into the combustion chamber is controlled by separate valves; the improvement which comprises means for operating said valves including a cam, a shaft, an arm rigidly

mounted on said shaft and operatively engaged by said cam to swing said arm in one direction, a member mounted on said arm and cooperating with said cam to swing said arm in the opposite direction, so that upon rotation of said cam, an oscillatory motion will be imparted to the shaft, said member being movable to vary the length of the portion thereof engageable by said cam to vary the cycle of the oscillatory motion imparted to said shaft, and a second arm rigidly mounted on the shaft and adapted to engage the air-valve-operating means and the fuel-valve-operating means, whereby the oscillatory motion of the shaft is imparted to said second arm to actuate the air-valve-operating means and the fuel-valve-operating means.

12. An internal combustion engine comprising a stationary cylinder head, a high pressure combustion cylinder reciprocable about said stationary cylinder head, means for introducing air and fuel into said high pressure cylinder for ignition, the products of combustion partially expanding in said high pressure cylinder, a low pressure cylinder in tandem relation with respect to said high pressure cylinder in which further expansion of the products of combustion takes place, a piston reciprocable in said low pressure cylinder having a port through which the gases from the high pressure combustion cylinder enter the low pressure cylinder for further expansion, means for controlling the passage of gases through said port, a housing surrounding said high pressure cylinder and closing one end of said low pressure cylinder, said low pressure cylinder having an air inlet and an air outlet in said end thereof, means for conducting air from said outlet to the air inlet for the high pressure cylinder, piston rings in the side walls of said low pressure piston for making a tight fit with the low pressure cylinder, and piston rings in said housing for making a tight fit with said reciprocable high pressure cylinder whereby on one of the strokes of said low pressure piston air will be compressed between said piston and said housing and forced through said air outlet for introduction into the high pressure cylinder through the air inlet means thereof.

13. An internal combustion engine comprising a stationary cylinder head, a high pressure combustion cylinder reciprocable about said stationary cylinder head, means for introducing air and fuel into said high pressure cylinder for ignition, the products of combustion partially expanding in said high pressure cylinder, a low pressure cylinder in tandem relation with respect to said high pressure cylinder in which further expansion of the products of combustion takes place, a piston reciprocable in said low pressure cylinder having a port through which gases from the high pressure combustion cylinder enter the low pressure cylinder at the side of said piston opposite said reciprocable high pressure cylinder for further expansion, means for controlling the passage of gases through said port, a housing surrounding said high pressure cylinder and closing one end of said low pressure cylinder, means for introducing air into said low pressure cylinder between said piston and said housing when the piston is moved to a position away from said stationary cylinder head, said low pressure cylinder having an outlet for air introduced into said low pressure cylinder between said piston and said housing, means for conducting air from said outlet to the air inlet of the high pressure cylinder, piston rings in the side walls of said low pressure piston for making a tight fit with the low pressure cylinder, and piston rings in said housing for making a tight fit with said reciprocable high pressure cylinder whereby as said piston moves toward said stationary cylinder head air introduced into said low pressure cylinder between said piston and said housing will be forced through said air outlet for introduction into the high pressure cylinder through the air inlet means thereof.

14. An internal combustion engine comprising a stationary cylinder head, a cylinder reciprocable about said stationary cylinder head and with said stationary cylinder head forming a high pressure combustion chamber into which constituents of a combustible mixture are introduced and in which combustion takes place and the products of combustion partially expand, a low pressure cylinder in tandem relation with respect to said high pressure cylinder in which further expansion of the products of combustion takes place, a piston reciprocable in said low pressure cylinder, means for introducing gases from the high pressure cylinder into said low pressure cylinder for further expansion, means for controlling the passage of gases from said high pressure cylinder to said low pressure cylinder, a water jacket next to said stationary cylinder head, a water jacket about said low pressure cylinder, a passage connecting said water jackets so that cooling water may flow serially through said water jackets, and means for directing water entering the water jacket next to said stationary cylinder head upwardly along one side thereof, around the top thereof and then downwardly along the opposite side thereof.

LELLIA L. WILLIAMS.
Administratrix of the Estate of Marcy L. Whitfield, Deceased.