This invention relates to fluid flow regulating systems and more particularly to fuel metering and control systems for combustion engines, this application being a division of applicant's co-pending application Serial No. 508,897 filed November 4, 1943, for Fuel Supply System.

The invention is particularly adapted for aircraft propulsion powerplants operating under varying conditions of barometric pressure, ambient temperature, thrust and speed.

An object of the invention is to provide an improved engine fuel control which automatically and under all operating conditions whether steady or transient maintains the ratio between engine fuel flow and engine air flow within predetermined upper and lower limits.

Another object is to provide an improved engine fuel control which automatically so regulates the fuel feed as to secure at all times proper combustion mixtures and maintain the temperatures resulting from combustion within desired safe limits.

The above and other objects will be apparent as the description proceeds. In the following description and in the claims various details will be identified by specific names for convenience, but they are intended to be as generic in the application as the art will permit.

The drawing, which shows an example of embodiment of the invention, is a sectional elevational view of a fuel metering device and diagrammatically indicates the connections thereof with the engine and the fuel nozzle valves.

In the specific embodiment of the invention which is here described, the engine 88 is shown as an internal combustion engine provided with an air induction system comprising a passage having an orifice or venturi 84 therein, a valve 85 and an engine-driven compressor 89 delivering air under pressure to a manifold 91 connected with the cylinder inlet ports leading to the combustion chambers.

The fuel system comprises an engine-driven fuel pump 47 which is supplied with liquid fuel at suitable pressure from a conduit 81 through an orifice 82 whose effective area is controlled by a slide valve 83. The pump discharges fuel always in excess of engine requirements, to the supply manifolds 45.

A number of fuel injectors 9 are provided, each having an intake port connected with one of the fuel supply manifolds 45, a nozzle valve through which fuel is delivered to the engine in quantity variable with the fuel pressure, and a return port in free communication with the inlet port and connected with one of the return manifolds 39 through which the excess fuel is circulated back to the inlet side of the pump 47, as described hereinafter. These fuel injectors or nozzle units 9 are not part of the present invention. One suitable type thereof, designed for intermittently discharging fuel into the engine cylinders is described and claimed in applicant's Patent No. 2,516,526 issued July 25, 1950. Another suitable type of injector or nozzle, well known in the art, consists essentially of a calibrated orifice through which a continuous spray of fuel is injected into the air stream in the engine air induction system or manifold.

The excess fuel which flows from the injection units 9 to the return manifolds 39 is led to a pressure regulating device or by-pass device 84 having a slideable valve 85 which controls a flow restricting orifice 87 through which the excess fuel flows back to the intake side of the pump 47, downstream of the orifice 82. The fuel flow through the latter orifice is thus equal to the engine fuel flow.

The valve 85 is actuated by two pressure responsive diaphragms 89 and 90. By means of conduits 91 and 92 the fuel pressure upstream and downstream of the orifice 82 is brought to bear upon opposite sides of the former diaphragm, thus applying to the valve 85 an axial load which increases with the engine fuel supply, in a direction to increase the effective area of the orifice 87.

The flexible diaphragm 90, connected at its center with the valve 85, has a cup-shaped outer portion whose periphery is secured to a co-operating cup-shaped member 101 connected with the resiliently loaded piston 102 of a hydraulic servomotor 103 controlled by a Venturi air density responsive bellows 104. By means of a conduit 105 and passages 107 and 108 the Venturi differential pressure is brought to bear on opposite sides of the diaphragm 90, thus transmitting to the valve 85 a load which increases with the Venturi air flow and tends to shift the valve in a direction to decrease the open area of the pressure regulating orifice 87. A bellows 109 connected with the cup member 101 serves to define higher and lower air pressure chambers within the diaphragm housing. The cup-member 101 and the diaphragm 90 are so designed that as the former slides towards the latter, an increasing annular outer portion of the diaphragm is caused by the air pressure differential to come into contact with the member 101, thereby decreasing the diaphragm area which is effective as pressure responsive means for the actuation of the valve 85. The effective diaphragm area is thus variably adjustable and is dependent upon the position of the piston 102.

Fluid under pressure, for example lubricating
oil from the engine, continuously flows into the cylinder chamber 111 through a small flow restricting orifice 112. This oil leaves the cylinder chamber through another orifice 113 formed in the piston 102 and controlled by a needle valve 114 connected to the bellows 104. Thus the piston constantly follows the needle 114 at definite distance therefrom without exerting any reaction on the bellows 104; when the latter contracts, the open area of orifice 113 increases, the oil pressure in chamber 111 drops, and the piston springs plus the differential air pressure on member 101 move the piston 102 toward the bellows. Conversely, when the latter expands, the effective area of orifice 113 decreases, and the increasing oil pressure in chamber 111 moves the piston away from the bellows.

The bellows 104 contains a definite mass of air or gas, and the walls thereof are so highly flexible as to expand or contract within the designed limits under negligible load. This bellows is surrounded by induction air in the immediate vicinity of the venturi, the air within the bellows thus being at the same pressure and temperature as the air flowing through the venturi, and therefore having the same density. As a result, the volume and in turn the length of the bellows are inversely proportional to the venturi air density.

The mass air flow per second W through the venturi may be calculated by the following formula

$$ W = K \sqrt{\delta I} $$

where $\delta$ is the Venturi air density and I is the Venturi pressure differential. In the above formula and in the following ones $K$ represents various constants dependent upon the geometrical and unchanging dimensions of the metering elements and, in some of the formulae, also upon the fuel density.

The load $P$ applied to the valve 85 by the diaphragm 90 is

$$ P = KD\sqrt{\frac{W^2}{\delta}} $$

wherein D is the effective diameter of the diaphragm that is, the diameter of the portion thereof which is not in contact with the cup member 101.

On the other hand the fuel flow per second $w$ through the orifice 82 is

$$ w = Ks \sqrt{\delta} $$

where $s$ is the variable effective area of the orifice 82, and $i$ is the fuel pressure drop across the orifice. The load transmitted to the valve 85 by the diaphragm 90 is

$$ p = Ki = K\sqrt{\frac{w^2}{\delta}} $$

The valve 85 is subject to the light load of an idling spring 115 adjustable by means of a threaded cap. However, when the engine operates at normal speed this spring load is negligible with respect to the loads $p$ and $P$. Furthermore, under the oppositely directed loads $p$ and $P$ the valve is in equilibrium. Substituting the relation $p = P$ in the above equations we obtain the following expression for the engine fuel-air ratio

$$ \frac{w}{W} = K \sqrt{\frac{D}{\delta}} $$

The diaphragm 90 and the cup member 101 are so designed that as the Venturi air density varies and the bellows 104 expands or contracts and shifts the cup member, the effective diameter of the diaphragm varies proportionally to the square root of the air density, thus rendering the fraction $D/\sqrt{\delta}$ constant. The fuel-air ratio then becomes $w/W = K_s$, in other words this ratio is determined by the adjustment of the needle valve 83 exclusively, irrespective of changes of altitude within the designed limits.

The profile of the cup member 101 and diaphragm 90 may readily be designed to satisfy the above requirement. If the axial length of the bellows 104 when subject to standard sea level air density is $L$, and the corresponding predetermined effective diameter of the diaphragm is $d$, at high altitude where the Venturi air density is one half of the standard sea level value the length of the bellows is $2L$, and owing to the changed position of the cup member relative to the diaphragm, the effective diameter of the latter will have to be 0.707 $d$. At higher altitude where the Venturi air density is one fourth of the standard value, the length of the bellows is 4 $L$, and the effective diameter of the diaphragm will be 0.5 $d$.

Manual as well as automatic control of the valve 83 may be provided to regulate the engine fuel-air ratio. Four cams are shown in the drawing for actuating this valve. The cam 116 is manually controlled by means of suitable linkage means. Cam 117 is connected to a manifold air pressure responsive bellows 118. Cam 119 is actuated in dependence upon the engine speed by a resiliently loaded diaphragm 120 responsive to the fuel pressure drop determined by an orifice 121 provided on the discharge side of the volumetric engine-driven pump 47, and cam 122 is actuated by a bellows 123 connected with an element 124 responsive to the manifold air pressure and preferably also responsive in predetermined degree to the engine cylinder temperature. The number, character and arrangement of the automatic devices connected with the fuel-air ratio control valve 83 may of course be varied to suit specific characteristics of various types of engines.

In operation, the fuel discharged under pressure by the pump 47 is led through the supply manifolds 45 to the various injectors 9; part of it is delivered to the engine, and the excess returns to the inlet port of the pump 47 through the return manifolds 39 and the by-pass orifice 87 controlled by the valve 85. When the valve 85 is set in its extreme left position, with the by-pass orifice 87 fully open, no appreciable amount of pressure is set up on the discharge side of the pump 47 or within the injectors 9, and the latter therefore do not deliver any fuel to the engine; the fuel discharged by the pump 47 is all returned to the inlet port thereof, no new fuel is admitted from the tank through the inlet pipe 81, and therefore no pressure drop is set up on the restriction 82 controlled by the valve 83. On the other hand, when the same valve 85 is in its extreme right position, reducing to a minimum the open area of the orifice 87, the pressure of the fuel on the discharge side of the pump 47 and in the injectors 9 attains its maximum value, the injectors 9 deliver to the engine their maximum designed fuel flow, and the flow of fuel from the tank through the restriction 82, and therefore the pressure drop across said restriction, attain their maximum value. It is thus clear that the valve 85 variably controls.
the pressure drop or pressure head across the restriction.

As already stated, the diaphragm exerts a load which is a measure of engine air flow; and any variation in the Venturi differential pressure in the pressure and/or temperature of the air surrounding the bellows actuates the valve to alter the pressure head across the restriction. Since any change in the speed of the engine is accompanied by a corresponding variation in engine air flow, it follows that any variation in engine speed will cause operation of the valve.

These embodiments of the invention have been shown merely for the purpose of illustration and not as a limitation of the scope of the invention. It is therefore expressly understood that the invention is not limited to the specific embodiment shown, but may be used in various other ways, in connection with other types of prime movers, that various modifications may be made to suit different requirements, and that other changes, substitutions, additions and omissions may be made in the construction, arrangement and manner of operations of the parts without departing from the limits or scope of the invention as defined in the following claims.

In interpreting the claims, where they are directed merely to less than all of the elements of the complete system disclosed, they are intended to cover possible uses of the rectified elements in installations which lack the non-rectified elements.

Certain features claimed herein are disclosed in my application Serial No. 401,353 filed July 7, 1941, now Patent No. 2,378,036 issued June 12, 1945.

I claim:

1. In a system for controlling the flow of liquid fuel to the combustion chamber of an engine, means defining a flow passage for the fuel having a variable feed restriction therein, a first valve for selectively varying the area of said restriction to accelerate and decelerate the engine, a speed governor arranged to be driven from the engine for actuating said first valve, a regulator valve movable to different positions to control the metering head across said restriction, means for automatically varying the position of said regulator valve with changes of engine speed, and means responsive to changes in pressure of the air flowing to the combustion chamber for modifying the action of the regulator valve.

2. In a system for controlling the flow of liquid fuel to the combustion chamber of an engine having an engine driven compressor for supplying air under pressure to the combustion chamber, means defining a flow passage for the fuel having a variable feed restriction therein, a first valve to selectively vary the area of the restriction, a speed governor for actuating said first valve, a regulator valve movable to different positions to adjust the metering head across said restriction, pressure responsive means connected to the regulator valve and means for automatically producing a differential across said pressure responsive means varying with variations in engine speed, and means responsive to changes in pressure of the air flowing to the compressor for modifying said differential.

3. In a system for controlling the flow of liquid fuel to an engine having a compressor supplying air under pressure, means defining a flow passage for the fuel having a variable feed restriction therein, a valve for varying the area of said restriction, a manually operable member oper-

4. In a system for controlling the flow of liquid fuel to an engine, means defining a flow passage for the fuel having a variable feed restriction therein, a valve for varying the area of said restriction, a manually operable member oper-

5. In a system for controlling the flow of liquid fuel to an engine driven speed governor also having an operative connection with said valve, a regulator valve movable to different positions to adjust the metering head across said restriction, pressure responsive means connected to the regulator valve, means for subjecting said pressure responsive means to a differential varying with variations in engine speed to automatically maintain the rate of fuel feed within predetermined limits during acceleration and deceleration, and means responsive to changes in pressure of the air flowing to the compressor for modifying said differential.

6. In a system for controlling the flow of liquid fuel to an engine, means defining a flow passage for the fuel having a variable feed restriction therein, a valve for varying the area of said restriction, a manually operable member oper-
vary the area of the restriction, a speed governor
acting on said valve, a regulator valve movable to
different positions to adjust the metering head
across said restriction, pressure responsive means
connected to the regulator valve, means for auto-
matically producing a differential across said
pressure responsive means varying with varia-
tions in engine speed, and means responsive to
changes in temperature of the air flowing to the
compressor for modifying said differential.

9. In a system for controlling the flow of liquid
fuel to an engine having an engine driven com-
pressor for supplying air under pressure, means
defining a flow passage for the fuel having a vari-
able feed restriction therein, a valve for varying
the area of said restriction, a manually operable
member operatively connected to said valve, an
engine driven speed governor also having an
operative connection with said valve, a regulator
valve movable to different positions to adjust the
metering head across said restriction, pressure re-
sponsive means connected to the regulator valve,
means for subjecting said pressure responsive
means to a differential varying with variations in
engine speed to automatically maintain the rate
of fuel feed within predetermined limits during
acceleration and deceleration, and means respons-
ive to changes in temperature of the air flowing
to the compressor for modifying said differential.

10. In a system for controlling the flow of fuel
to an engine, means defining a flow passage for
the fuel having a metering restriction therein,
a valve for varying the area of said restriction,
a governor adapted to be driven by the engine
and operatively connected to said valve for au-
tomatically positioning the same, manually operable
at the will of a pilot for varying the ad-
justment of said valve, and means responsive to
changes in temperature of the air flowing to
the engine for automatically varying the meter-
ing head across said metering restriction at any
given position of the valve.

11. In a system for controlling the flow of
liquid fuel to an engine, means defining a flow
passage for the fuel having a variable feed re-
striction therein, a first valve for selectively
varying the area of said restriction, speed re-
sponsive means arranged to be driven from the
engine for actuating said first valve, a regulator
valve movable to different positions to control the
metering head across said restriction, means for
automatically varying the position of said regu-
lating valve upon changes of engine speed and
means responsive to changes in temperature of
the air flowing to the engine for modifying the
action of the regulator valve.

12. In a system for feeding fuel to an engine,
a conduit supplying fuel to said engine, a meter-
ing restriction in the conduit, means for regu-
lating the pressure drop across the restriction,
and means for automatically varying the effec-
tive area of the restriction with changes in en-
gine speed.

13. In a system for supplying liquid fuel to
an engine, one or more fuel discharge nozzles,
a pump for supplying fuel under pressure to said
nozzles, a fuel conduit communicating said pump
with said nozzles and having a metering restric-
tion therein upstream of the nozzles, adjustable
valve means for varying the flow through said
restriction, manual means for adjusting said
valve means, an engine driven governor oper-
atively connected to said valve means for auto-
matically adjusting the latter, and means re-
sponsive to changes in the pressure of the air
flowing to the engine arranged to adjust the
flow through said restriction independently of
said governor.

14. In an engine fuel control having a fuel pas-
sage, a restriction therein, first means moveable
to control the effective area of said restriction,
second means for regulating the pressure head
across said restriction, means actuating said sec-
ond means to vary said pressure head under
varying values of engine air flow so as to main-
tain for each setting of said first means a cor-
responding substantially constant fuel to air
ratio, and means including manually operable
valves and engine speed responsive means for
variably positioning said first means withina
predetermined range of motion to vary the fuel
to air ratio within predetermined rich and lean
limits.

15. Regulating apparatus for a powerplant in-
cluding a fuel feeding system, a fuel feed valve
therein, a governor or like speed responsive de-
vice for actuating said valve, and means respon-
sive to variations in air density for regulat-
ing the pressure head across said valve.

16. Regulating apparatus for a powerplant in-
cluding a fuel feeding system, a fuel feed valve
therein, a governor or like speed responsive de-
vice for actuating said valve, and means respon-
sive to variations in air temperature for regu-
larizing the pressure head across said valve.

17. Regulating apparatus for a powerplant in-
cluding a fuel feeding system, a fuel feed valve
therein, a governor or like speed responsive de-
vice for actuating said valve, and means respon-
sive to variations in air density for regulating
the pressure head across said valve.

18. Regulating apparatus for a powerplant in-
cluding a fuel feeding system, a fuel feed valve
therein, a governor or like speed responsive de-
vice for actuating said valve, and means respon-
sive to variations in operating conditions affect-
ing powerplant air flow for regulating the pres-
sure head across said valve.

19. Regulating apparatus for a powerplant in-
cluding a fuel feeding system, a fuel feed valve
therein, a governor or like speed responsive de-
vice for actuating said valve, and means respon-
sive to variations in air density for regulating
the pressure head across said valve in accordance
with powerplant air flow.

20. For use in a fuel supply system for power-
plants having a combustion space to which air
is supplied under pressure, a fuel conduit hav-
ing a variable metering restriction therein, means
for creating a flow of fuel through said conduit,
an element for varying the area of said restric-
tion, a governor driven from said powerplant
and operatively connected to said element, a regu-
lating valve arranged to vary the flow of fuel
through said restriction, pressure responsive
means operatively connected to said valve
and arranged to respond to the drop across said
restriction, means for regulating the pres-
sure differential across said pressure responsive
means, and means responsive to changes in pres-
sure of the air flowing to the combustion space
for modifying the differential across said pres-
sure responsive means.

21. For use in a fuel supply system for power-
plants having a combustion space to which air
is supplied under pressure, a fuel conduit hav-
ing a variable metering restriction therein,
means for creating a flow of fuel through said
conduit, an element for varying the area of said
restriction, a governor driven from said power-
plant and operatively connected to said

element, a regulating valve arranged to vary the flow of fuel through said restriction, pressure responsive means operatively connected to said valve and arranged to respond to the drop across said restriction, means for regulating the pressure differential across said pressure responsive means, and means responsive to changes in temperature of the air flowing to the combustion space for modifying the differential across said pressure responsive means.

22. A device for regulating the fuel feed of aircraft powerplants, comprising a fuel conduit having a feed restriction therein, a feed valve controlling said restriction, means for actuating said feed valve including a control member and a governor driven from the powerplant, means for regulating the differential pressure across said feed valve, and means for varying said differential in relation to changes in entering air density.

23. In a fuel control device for controlling the flow of fuel to the combustion space of a powerplant having a prime mover, a fuel supply conduit, a first valve in said conduit, a governor arranged to be driven by said prime mover for controlling said first valve, a by-pass valve arranged to regulate the fuel metering head across said first valve, and means responsive to changes in condition of the air flowing to said combustion space for actuating said by-pass valve.

24. An engine fuel supply system including an adjustable metering valve, an adjustable pressure regulating valve in series with said metering valve, an engine-driven positive displacement pump having an outlet duct with a constriction therein located to pass the whole output of said pump, a pressure responsive member sensing variations in pressure difference across said constriction, and means connecting said pressure responsive member to said metering valve to actuate the latter upon changes in said pressure difference.

25. In or for a thermal powerplant having a first system for the supply of a first fluid and a second system for the supply of a second fluid, a fluid flow control orifice in said first system, a valve for controlling said orifice, a first device responsive to a speed condition of the powerplant and a second device responsive to pressure in a portion of said second system for positioning said valve, a by-pass valve for controlling the pressure drop across said orifice, said by-pass valve having wall means movable therewith for subacting the by-pass valve to fluctuating pressures operating in opposite directions, connections from the upstream and downstream sides of said orifice to opposite sides of said wall means for positioning the by-pass valve in accordance with the difference in pressure across said orifice, and a spring connected to bias said by-pass valve in a direction assisting the pressure on the downstream side of the orifice.

26. In a valve control system for fluid delivery apparatus for a thermal powerplant, a fluid flow control orifice, a valve for controlling said orifice, a first device responsive to a speed condition of the powerplant and a second device responsive to a temperature condition of the powerplant for positioning said valve, a by-pass valve for controlling the pressure drop across said orifice, said by-pass valve being provided with movable wall means for subjecting the by-pass valve to pressures operating in opposite directions, connections from the upstream and downstream sides of said orifice to opposite sides of said wall means for positioning the by-pass valve in accordance with the difference in pressure across said orifice, and resilient means connected to bias said by-pass valve in a direction assisting the pressure on the downstream side of said orifice.

27. In or for a thermal powerplant, a first fluid supply system including fluid discharge units, fluid conduit means interconnecting said units, a control device including a metering orifice connected with said conduit means for controlling the fluid discharge of said units, a first valve controlling said orifice, a device responsive to a speed condition in said powerplant for controlling said valve, first pressure responsive means subject to the difference in pressure between a point upstream of said orifice and a point downstream thereof, a second valve for varying the pressure head across said orifice, a second system for supplying another fluid to said powerplant, venturi means in the second system, second pressure responsive means subject to the venturi differential pressure, and an operative connection for actuating the second valve from said first and second pressure responsive means.

28. For an engine having an air intake system with a venturi therein and a fuel supply system comprising a plurality of fuel discharge units and fuel conduit means interconnecting said units, a control device comprising an orifice for metering the fuel flow to said units, a first valve controlling said orifice, engine speed responsive means for positioning said valve, a second valve for varying the pressure head across said orifice, and venturi means for actuating said venturi valve.

29. In a thermal powerplant having a first fluid supply system, a second fluid supply system, a valve controlling a metering orifice in the first fluid supply system, a device responsive to a speed condition in said powerplant, a device responsive to a temperature level in said powerplant and a device responsive to pressure in a portion of said second fluid supply system for actuating said valve, a by-pass valve movable to control the pressure head across said orifice, and means for subjecting said by-pass valve to the pressure difference between upstream and downstream sides of said orifice.

30. For an engine having an air induction system with Venturi means and an air compressor therein, a fuel supply system including a fuel passage, a first valve for restricting fuel flow in said passage, engine speed and temperature responsive means for actuating said valve, a second valve for varying the pressure head across said first valve, and Venturi differential pressure responsive means for actuating said second valve.

31. For an engine having a supercharger, an intake system leading air to the supercharger, a manifold leading air from the supercharger to the engine cylinders, and Venturi means in said intake system: a fuel supply system including a fuel passage; a flow restricting orifice in said passage; a first valve controlling said orifice; engine speed and temperature responsive means and manifold pressure responsive means for actuating said valve; a second valve for controlling the pressure head across said orifice; and means responsive to Venturi differential pressure and means responsive to pressure differences between spaced points of said fuel supply system for controlling said second valve.

32. For an engine having at least one combustion chamber, an air induction system with a
compressor therein for supplying air to said combustion chamber and a fuel system with a pump therein for supplying fuel to said combustion chamber; a fuel control device including a fuel passage with a flow restricting orifice therein; a first valve for controlling said orifice; manually operable means, engine speed responsive means, engine temperature responsive means and means responsive to pressure in a portion of said air induction system for actuating said valve; a second valve for regulating the pressure head across said orifice; and conduit means for subjecting said second valve to the pressure in a portion of said fuel system upstream of said orifice and to the pressure in a portion of the same system downstream of said orifice.

33. In a system for supplying liquid fuel to an engine, one or more fuel discharge nozzles, a pump for supplying fuel under pressure to said nozzles, a fuel conduit communicating said pump with said nozzles and having a metering restriction therein upstream of the nozzles, adjustable valve means for varying the flow through said restriction, manual means for adjusting said valve means, an engine driven governor operatively connected to said valve means for automatically adjusting the latter, and means responsive to changes in the density of the air flowing to the engine arranged to adjust the flow through said restriction independently of said governor.

34. In a system for supplying liquid fuel to an engine, one or more fuel discharge nozzles, a pump for supplying fuel under pressure to said nozzles, a fuel conduit communicating said pump with said nozzles and having a metering restriction therein upstream of the nozzles, adjustable valve means for varying the flow through said restriction, manual means for adjusting said valve means, an engine driven governor operatively connected to said valve means for automatically adjusting the latter, and means responsive to changes in engine speed, and means for automatically varying the effective area of said restriction with variations of engine induction air pressure.

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