United States Patent [19]

Miller

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[54] **APPARATUS FOR CONTROLLING A FUEL INJECTED ENGINE DRIVING A VARIABLE PITCH PROPELLER**

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[73] Assignee: **Woodward Governor Company**, Rockford, Ill.

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[52] **U.S. Cl.** **416/28**; 416/29

[51] **Int. Cl.** **B64c 11/32**

[58] **Field of Search** 416/29, 28, 27, 30

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[57] **ABSTRACT**

By positioning a single power member, the pilot of an aircraft having a fuel injected engine and a variable pitch propeller may select a desired power level and automatically establish the engine speed, fuel flow and manifold pressure settings which will best develop the selected power. Manifold pressure is trimmed automatically in response to changes in altitude and outside temperature.

10 Claims, 4 Drawing Figures

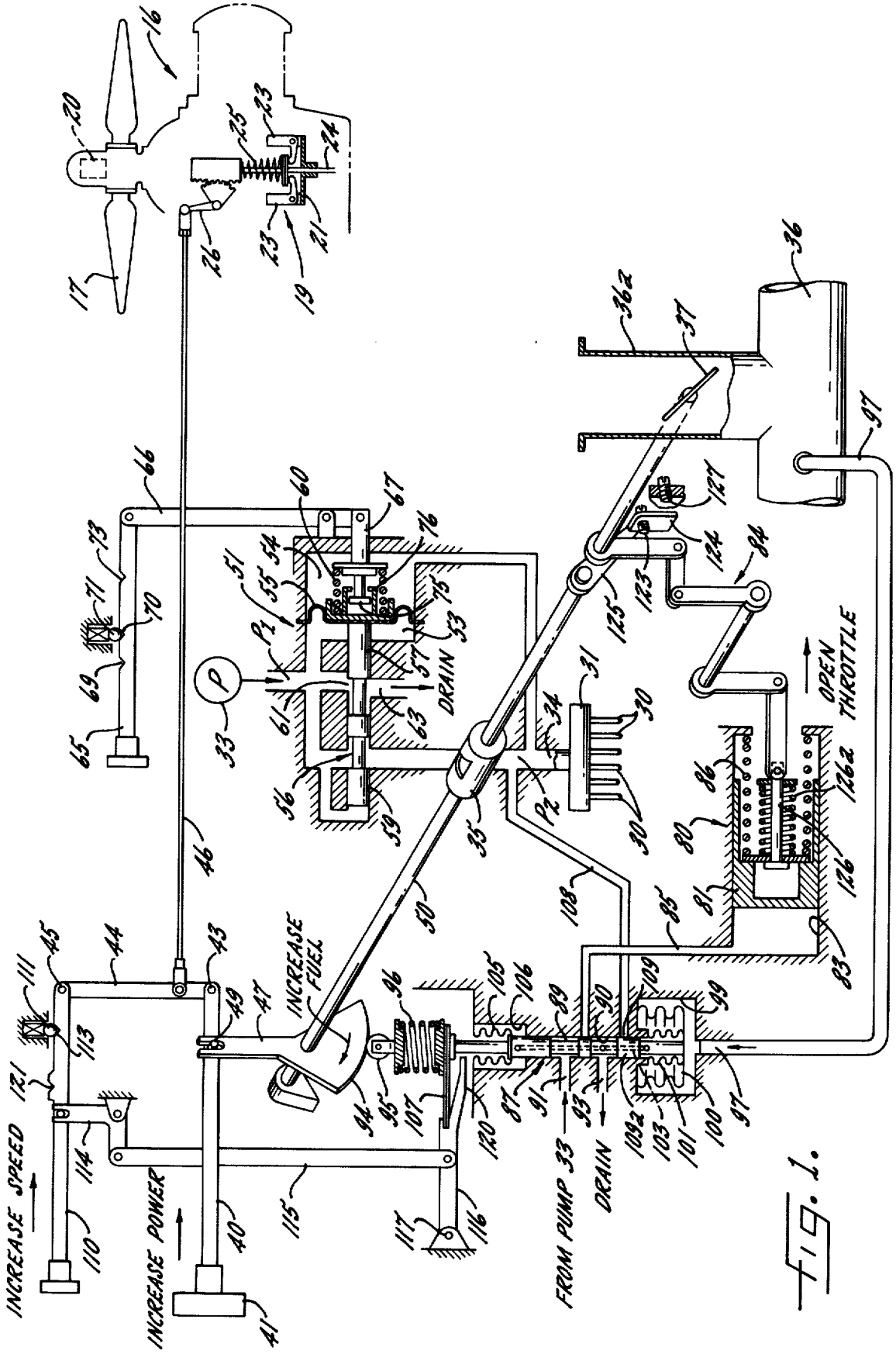

INCREASE SPEED
INCREASE POWER
INCREASE FUEL
FROM PUMP 33
DRAIN
DRAIN
OPEN THROTTLE

FIG. 1.

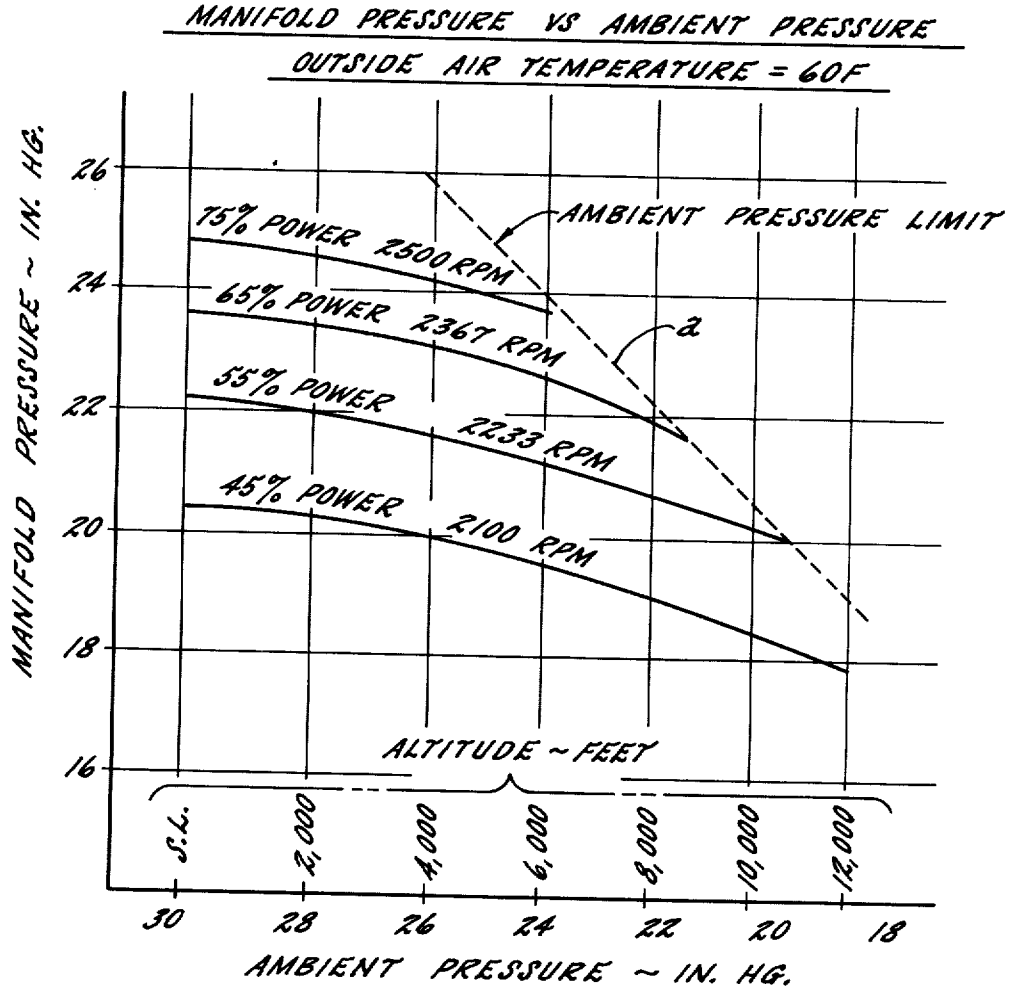

MANIFOLD PRESSURE VS AMBIENT PRESSURE
OUTSIDE AIR TEMPERATURE = 60F
MANIFOLD PRESSURE ~ IN. HG.
26
24
22
20
18
16
75% POWER 2500 RPM
65% POWER 2367 RPM
55% POWER 2233 RPM
45% POWER 2100 RPM
AMBIENT PRESSURE LIMIT
a
ALTITUDE ~ FEET
S.L.
2,000
4,000
6,000
8,000
10,000
12,000
30
28
26
24
22
20
18
AMBIENT PRESSURE ~ IN. HG.

Fig. 2.

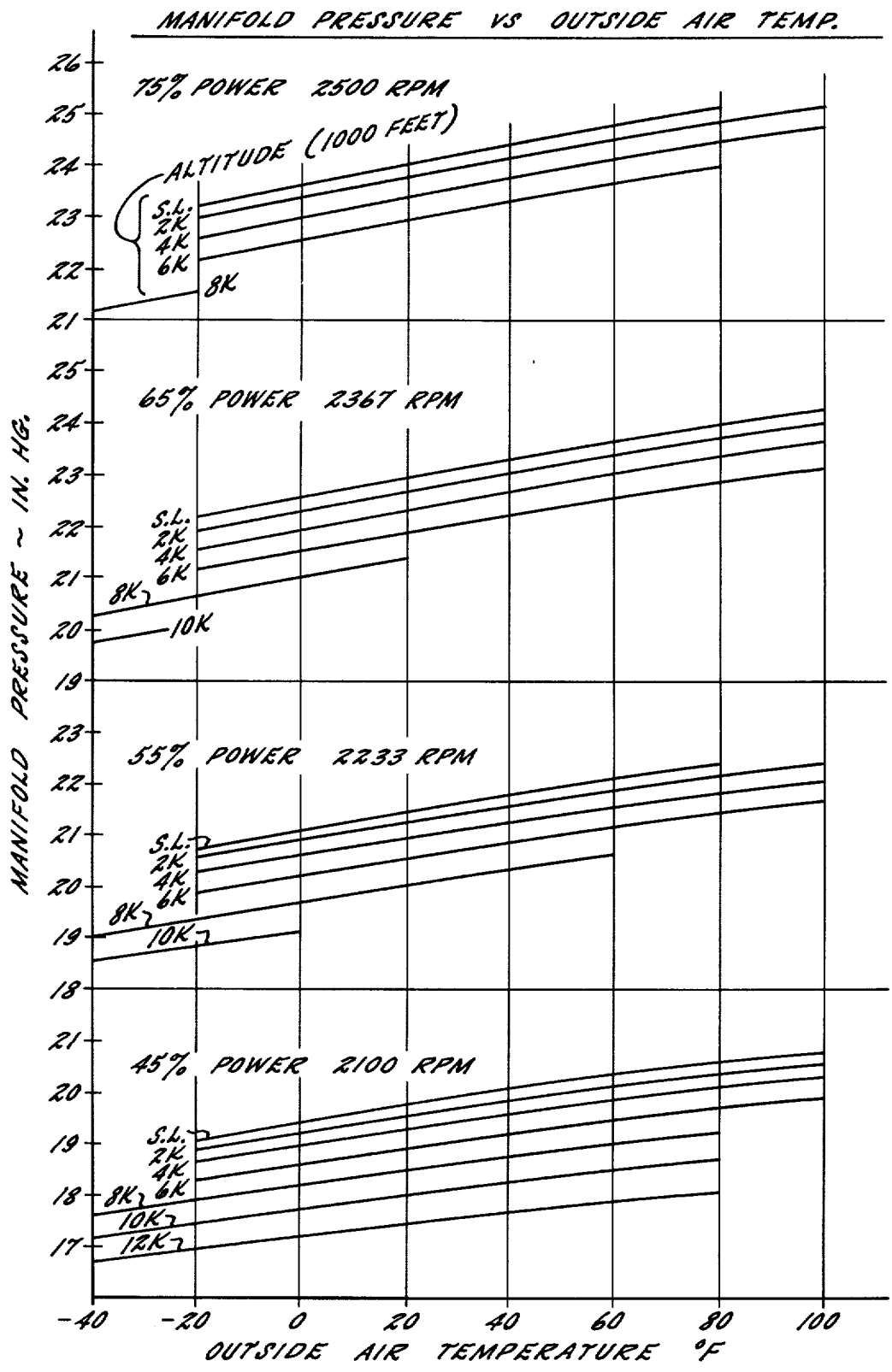

MANIFOLD PRESSURE VS OUTSIDE AIR TEMP.
75% POWER 2500 RPM
ALTITUDE (1000 FEET)
S.L.
2K
4K
6K
8K
65% POWER 2367 RPM
S.L.
2K
4K
6K
8K
10K
55% POWER 2233 RPM
S.L.
2K
4K
6K
8K
10K
45% POWER 2100 RPM
S.L.
2K
4K
6K
8K
10K
12K
MANIFOLD PRESSURE ~ IN. HG.
OUTSIDE AIR TEMPERATURE °F
-40
-20
0
20
40
60
80
100

Fig. 3.

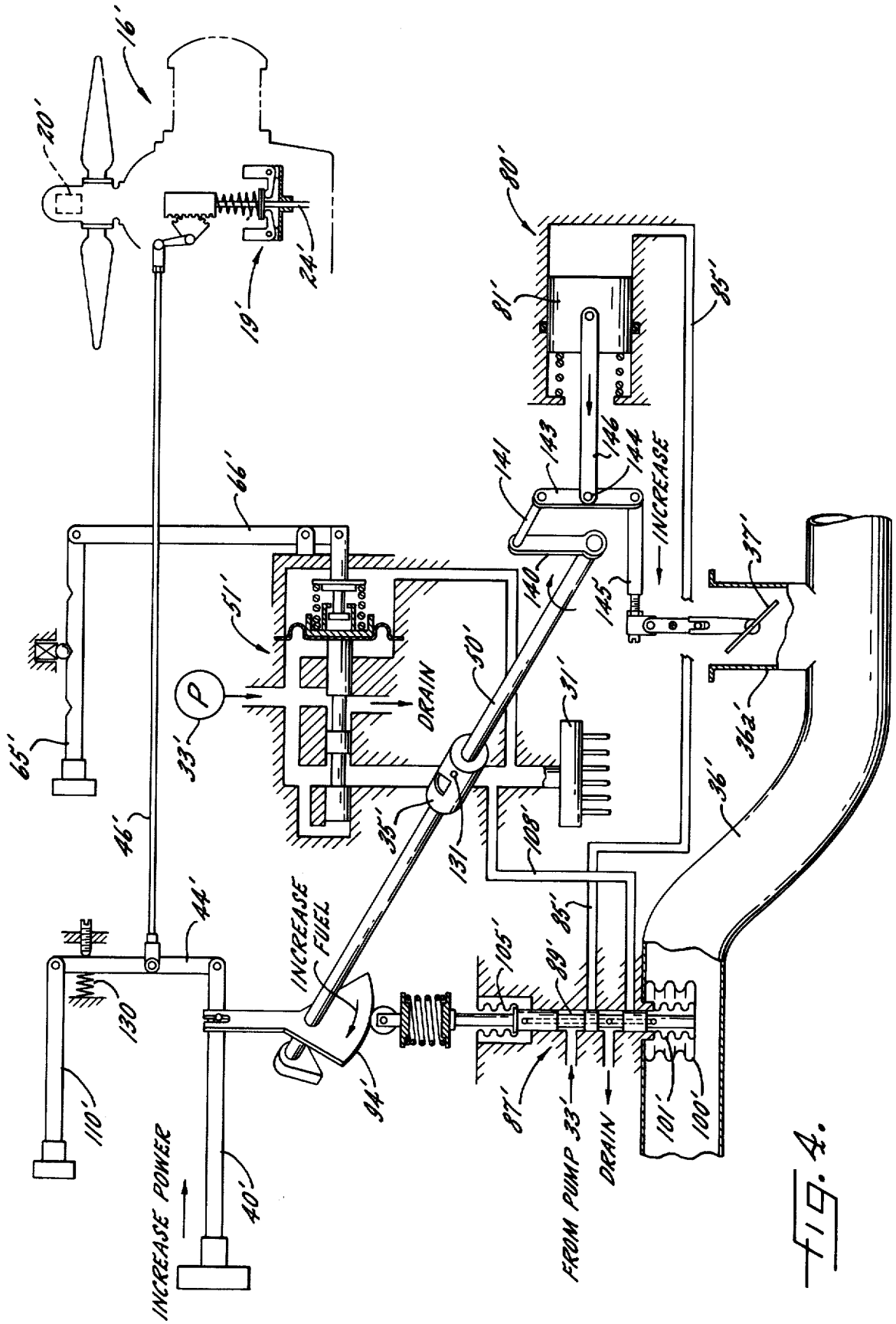

16'
20'
24'
19'
80'
81'
83'
141
143
146
144
INCREASE
66'
140
145'
37'
51'
50'
DRAIN
P
33'
65'
46'
31'
362'
36'
35'
131
108'
44'
INCREASE FUEL
105'
89'
85'
130
94'
87'
101'
100'
110'
INCREASE POWER
40'
FROM PUMP 33'
DRAIN

FIG. 4.

APPARATUS FOR CONTROLLING A FUEL INJECTED ENGINE DRIVING A VARIABLE PITCH PROPELLER

BACKGROUND OF THE INVENTION

This invention relates to apparatus by which the pilot of an aircraft may control the power output of an internal combustion engine connected to drive a variable pitch propeller. Such an engine is conventionally equipped with a governor which may be manually set to establish a selected engine speed and which keeps the engine turning at substantially the selected speed under varying flight conditions by adjusting the pitch of the propeller to change the load on the engine. The engine further includes a throttle which may be manually adjusted to change the flow of combustion air to the engine. When the engine is running at a given speed and the throttle is opened manually, the pressure in the intake manifold of the engine is increased and the mass flow of fuel and air to the engine also in increased to cause the engine to develop more power.

For a given engine to develop a given power while still operating safely and economically, the governor and the throttle should be set to cause the engine to run at a particular speed and a particular manifold pressure for each different power level at which it is desired to operate the engine, the particular values being specified by the engine manufacturer. Thus, for each power level, there exists a recommended engine speed which the pilot may establish by setting the governor and which remains constant regardless of changes in ambient conditions. Manifold pressure to maintain the set power, however, is dependent not only upon the throttle setting and engine speed but also upon the pressure of the ambient atmosphere in which the aircraft is flying. Thus, with the engine at given speed and throttle settings, manifold pressure decreases as ambient pressure decreases when the aircraft increases altitude. If the throttle setting is not changed to compensate for the effects of ambient pressure, the engine will not develop power at the desired level.

Accordingly, the engine manufacturer recommends that the throttle be adjusted to establish different manifold pressures at different altitudes. When altitude is increased, the throttle is opened to prevent the manifold pressure from dropping off sharply but, with progressive increases in altitude, is opened to such positions as to establish progressively lower manifold pressures.

The engine manufacturer also recommends that different manifold pressures be maintained for different ambient temperatures. With progressive temperature increases, the throttle should be opened to establish progressively higher manifold pressures.

More particularly, the present invention relates to control apparatus for fulfilling the same general purposes as the control apparatus disclosed in Meyer U.S. application Ser. No. 329,211, filed Feb. 2, 1973 and now abandoned, said application being assigned to the assignee of the present invention. Such apparatus simplifies the tasks of the pilot by enabling the pilot to adjust a single control member to select a desired power level and, as an incident to such adjustment, to automatically establish the correct speed and throttle settings necessary to properly achieve the desired power level at any temperature or altitude. As a result of the single control member, the pilot is relieved of the burden of first determining the proper speed and throttle settings for a given power level, temperature and altitude and then manipulating individual controls to establish these settings.

SUMMARY OF THE INVENTION

The general aim of the present invention is to provide new and improved single member control apparatus which is simpler in construction than prior apparatus of the same general type and which, at the same time, more accurately establishes the proper manifold pressure.

A more detailed object is to provide novel control apparatus which sets and adjusts the throttle as a function of manifold pressure so that the recommended manifold pressures can be followed more accurately than is the case when the throttle is adjusted to predetermined positions estimated to produce the proper manifold pressure.

An important object of the invention is to provide unique single member control apparatus which is especially suitable for use with engines having fuel injection systems.

A related object is to provide control apparatus in which flow of fuel to the engine is scheduled directly as a function of the position of the control member, the throttle being uniquely controlled to cause mixing of the proper amount of combustion air with the fuel and to establish the proper manifold pressure.

Another important object is to automatically reduce the flow of fuel to the engine when the aircraft is flying at such high altitudes that the manifold pressure for obtaining the desired power level cannot be maintained.

Still another object is to provide means with which the pilot may optionally select an engine speed different from the recommended speed while still maintaining the same power level.

These and other objects and advantages of the invention will become more apparent from the following detailed description when taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a diagrammatic view schematically showing one embodiment of the new and improved control apparatus of the present invention associated with an exemplary aircraft engine.

FIG. **2** is a family of curves which show the recommended manifold pressures for various ambient pressures and various constant power levels.

FIG. **3** shows several families of curves which illustrate the recommended relationship between outside air temperature and manifold pressure at various power levels and altitudes.

FIG. **4** is a diagrammatic view showing another embodiment of the control apparatus.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

For purposes of illustration, the invention is shown in the drawings as embodied in apparatus for controlling a prime mover which herein is a reciprocating piston internal combustion engine **16** of the type commonly used in an aircraft to rotate a variable pitch propeller **17.** The engine includes a conventional governor **19** which responds to changes in the engine speed brought about by varying flight conditions such as fluctuations

in air speed and density. In response to such changes, the governor causes actuation of a hydraulic servomotor **20** to increase or decrease the propeller blade angle and thus adjust the load on the engine so that the load will keep the engine running at a constant desired speed at a given horsepower setting which is selected by the pilot to suit flight conditions.

The governor **19** includes a rotatable head **21** driven by the engine **16** and pivotally supporting flyballs **23** which are connected to a rod **24** urged downwardly by an adjustable speeder spring **25** and actuating a valve (not shown) for regulating the flow of pressure fluid to and from the servo **20.** The speed of the engine is maintained at a constant desired value determined by the adjustment of the speeder spring, such adjustment being effected by moving a speed setting control element **26** whose position may be adjusted manually by the pilot from inside the cockpit. A gage (not shown) is located in the cockpit to enable the pilot to determine the engine speed.

In this instance, the engine **16** is equipped with a fuel injection system with which fuel is delivered into the individual cylinders through injection nozzles (not shown) communicating with fuel lines **30** which, in turn, communicate with a divider valve **31.** An engine-driven pump **33** delivers fuel to the divider valve through a line **34** at a rate determined primarily by the position of a rotary metering valve **35** which may be adjusted manually by the pilot.

Air for supporting combustion of the fuel is admitted into the intake manifold **36** of the engine **16** through an air intake unit **36a** having a pivoted butterfly valve **37** which constitutes the throttle of the engine. By manually opening and closing the throttle **37,** the pilot may increase and decrease the mass rate of flow of the fuel-air mixture and thereby increase and decrease the power developed by the engine. As the throttle **37** is opened and closed, the pressure in the intake manifold **36** increases and decreases, respectively, such pressure being reflected on a gage (not shown) in the cockpit and, when taken with engine speed and fuel flow, providing a measure of the power developed by the engine.

If the throttle **37** is at a given setting, the manifold pressure will change when the engine speed is changed and also will change as an incident to changes in the pressure of the ambient atmosphere. That is, if engine speed is reduced, it is necessary to open the throttle and raise the manifold pressure in order to maintain the same power at the reduced speed. When ambient pressure decreases as a result of an increase in altitude, manifold pressure will decrease unless the throttle is opened to compensate for the decreased pressure of the atmosphere. Also, the throttle should be adjusted as the temperature of the ambient atmosphere changes and should be opened to a greater degree at higher temperatures so as to establish higher manifold pressures and prevent power from dropping off.

In order to enable the engine **16** to operate safely and with peak fuel economy at a given power output, the engine manufacturer specifies that the pilot establish a particular engine speed and a particular manifold pressure for each power level at which the pilot desires to run the engine. For one particular engine, the recommended engine speeds and manifold pressures for each power level are shown by the curves of FIGS. **2** and **3.** From the curves, it will be seen that a different speed is specified for each different power level but that each speed is of constant value regardless of ambient pressure and temperature. The specified manifold pressure, however, varies as a function of ambient temperature and pressure since different manifold pressures are required to maintain the same power level at different temperatures and altitudes. As shown by the curves, the engine manufacturer specifies progressively higher manifold pressures at progressively higher temperatures and specifies progressively lower manifold pressures for progressively lower ambient pressures, the recommended manifold pressure thus drooping off as altitude is increased and ambient pressure decreases.

With most propeller-driven aircraft, the pilot must decide upon the power level and altitude he wishes to maintain and then consult tables, curves or the like to determine the speed and manifold pressure which are specified for the selected power level and altitude and for the then-existing outside temperature. The pilot then must manually set individual controls to set the speed control element **26** and the throttle **37** to the proper positions to maintain the specified speed and manifold pressure. If the pilot wishes to change altitude while still maintaining the same power level, he must determine the new manifold pressure and then readjust the throttle to establish the new pressure. Similarly, the throttle should be adjusted if the outside temperature changes by any significant extent.

Like the control apparatus disclosed in the aboveidentified Meyer application, the present apparatus simplifies the tasks of the pilot by enabling him to select a desired power level simply by positioning a single adjustable control member **40.** As an incident to positioning the control member **40** of the present apparatus, the speed control element **26** is adjusted to establish the specified speed for the selected power level and, at the same time, the throttle **37** is automatically adjusted to establish the manifold pressure which is specified for the particular power level, altitude and temperature. If either altitude or temperature changes, the throttle is automatically adjusted to establish the manifold pressure at the value specified for the changed conditions.

The present invention contemplates the provision of new and comparatively simple single member control apparatus which is particularly adapted for use with engines **16** of the fuel injected type and which sets the throttle **37** in such a manner as to make the actual manifold pressure of the engine more accurately correspond to the value specified by the engine manufacturer. With the present apparatus, both the speed of the engine and the rate of fuel flow are normally scheduled directly as a function of the position of the control member **40.** Adjustment of the control member also initiates movement of the throttle to change the manifold pressure and, in carrying out the invention, the actual manifold pressure is sensed in order to cause the throttle to be set in a position in which the actual manifold pressure corresponds to the specified pressure. In order that the pressure and temperature of the ambient atmosphere may be taken into account in establishing the manifold pressure, provision is made to sense ambient pressure and temperature and to properly adjust the throttle for different ambient conditions.

More specifically, the control member **40** (hereinafter called the power member) is in the form of an elongated rod whose outer end carries a fixed knob **41.** The inner end of the power member is pivotally connected at **43** to the lower end of an upright lever **44** whose

upper end is supported to swing about a normally fixed pivot **45**. An elongated link **46** is connected at its inner end to the lever **44** and is connected at its outer end to the speed control element **26** of the governor **19**. As the power member **40** is pushed inwardly or forwardly (i.e., to the right in FIG. **1**), the speed control element is swung in a clockwise direction to increase the speed setting of the governor. The ratio of the linkage between the power member **40** and the speed control element **26** is such that movement of the power member to each of its various power level positions sets the governor at the speed recommended for that power level. Thus, for the present engine, movement of the power member to tis 45% power position establishes a speed of 2100 RPM, movement of the power member to its 55% power position establishes a speed of 2233 RPM and so on.

To schedule fuel flow as a function of the position of the power member **40**, an arm **47** is coupled to the power member **40** by a pin-and-slot connection **49** and is connected to a fuel control element which herein is shown as being a rotatably supported shaft **50**. The shaft **50** is connected to the fuel metering valve **35** and rotates the valve as the power member is moved inwardly and outwardly, inward movement of the power member serving to move the valve clockwise to increase the rate of fuel flow.

In order to keep the fuel flow at the rate scheduled by the power member **40**, a constant pressure drop is maintained across the inlet and outlet of the metering valve **35** so that the flow rate through the valve is directly related to the position of the valve. For this purpose, a differential pressure valve **51** is located between the fuel pump **33** and the fuel metering valve **35** and includes a chamber which is divided into two compartments **53** and **54** by a flexible diaphragm **55** carrying a valve member **56** having spaced lands **57** and **59**. Pump pressure P1 is transmitted to the compartment **53** and to one end of the land **59** and is opposed by a spring **60** in the compartment **54** and by the fuel discharge pressure P2 in the line **34**. If the pump pressure P1 rises, the valve member **56** is moved to the right to cause the land **57** to open up a bypass port **61** and divert fuel away from the metering valve **35** and back to the fuel tank through a return line **63**. Conversely, a rise in the fuel discharge pressure P2 moves the valve member to the left to close off the bypass port **61** until the pump pressure P1 rises to a sufficient value to maintain the desired constant pressure drop across the fuel valve **35**, the particular drop being determined by the degree of compression in the spring **60**. Accordingly, when the spring **60** is set with a given compression, the rate of fuel flow to the engine **16** is directly related to the position of the fuel valve **35**.

When the aircraft is taking off and climbing, it is desirable to supply additional fuel to the engine **16** for cooling purposes but to supply such additional fuel without changing the position of the fuel valve **35** as scheduled by the power member **40**. This is achieved through the provision of a mixture control member **65** whose inner end is pivotally connected to a lever **66** which, in turn, is connected to a rod **67**. The spring **60** is compressed between the rod **67** and the diaphragm **55** and thus, when the rod is moved to the left, the compression in the spring is increased so as to shift the valve member **56** to the left and increase the flow of fuel to the fuel metering valve **35** so that more fuel is delivered to the engine even though the position of the fuel valve is not changed. Movement of the rod **67** to the right causes the spring **60** to relax to reduce the fuel flow to the engine.

As shown, the mixture control member **65** includes two detent notches **69** and **70** which coact with a spring-loaded detent **71** to hold the mixture member in different positions. When taking off and climbing, the pilot may push the mixture member inwardly until the detent **71** seats in the notch **69** and, with the mixture member in this position, the differential pressure valve **51** is set to deliver the desired additional fuel to the engine. After cruising altitude has been reached, the mixture member may be pulled outwardly to seat the detent in the notch **70** and set the differential pressure valve **51** to establish the proper pressure drop for cruising solely under the control of the power member **40**.

By pulling the mixture member **40** outwardly sufficiently far to seat the detent **71** in a third notch **73**, the pilot may shift the valve member **56** to the extreme right to cause the land **57** to fully open the bypass port **61** and the land **59** to fully close the passage leading to the fuel valve **35** and thereby cut off the flow of fuel to the engine **16** and unload the pump **33**. As the mixture lever is pulled outwardly to its cut-off position, a button **75** on the end of the rod **67** engages an extension **76** on the diaphragm **55** and shifts the valve member **56** to the right.

Movement of the throttle **37** is effected by a throttle servo **80** having a piston **81** slidable in a cylinder **83** and connected to the throttle by means of a pivoted linkage **84**. As pressure fluid is admitted into the left end of the cylinder through a line **85**, the piston **81** is shifted to the right to open the throttle. When pressure fluid is dumped from the left end of the cylinder, a spring **86** shifts the piston to the left to close the throttle.

The throttle servo **80** is controlled by a pilot valve **87** having a valve spool **89** which is adapted to slide downwardly within a bore **90** to connect the servo line **85** with a line **91** leading to a source of pressure fluid such as the pump **33**. With the valve spool **89** in its downward position, fuel under pressure is delivered to the throttle servo **80** to open the throttle **37**. When the valve spool is shifted upwardly from the position shown in FIG. **1**, the servo line **85** communicates with a drain line **93** and thus the throttle piston **81** may return to the left to close the throttle.

In keeping with the invention, movement of the power member **40** to a selected power level position serves to adjust the pilot valve **87** to change the setting of the throttle **37** and establish the manifold pressure which is specified for the selected power level, the throttle being moved until the actual manifold pressure corresponds to the pressure dictated by the position of the power member and by ambient pressure and temperature. For these purposes, the arm **47** carries a throttle control element in the form of a cam **94** which rides against a roller follower **95** located at the upper end of a compression spring **96** whose lever end bears against the upper end of the spool **89** of the pilot valve **87**. As the power member **40** is pushed inwardly to increase power, the cam **94** is rocked clockwise and acts through the follower **95** and the spring **96** to shift the valve spool **89** downwardly and cause opening of the throttle to increase the manifold pressure. The cam is shaped to schedule the manifold pressure at values which are properly correlated with the engine speeds

stablished at different positions of the power member **0.** As the cam is adjusted, a pressure signal is transmitted from the intake manifold **36** to the pilot valve **87** to ause the throttle to assume a position establishing the ctual manifold pressure at a value which corresponds the commanded value.

To transmit the manifold pressure signal, a line **97** eads from the manifold **36** to a chamber **99** which ouses an evacuated bellows **100** connected to the wer end of the valve spool **89** and sealed from the alve bore **90** by a second bellows **101,** the latter communicating with the drain line **93** through a passage **03** in the valve spool and being filled with fuel at drain ressure. As manifold pressure increases and decreases, the bellows **100** contracts and expands, respecvely, to shift the valve spool **89** upwardly and downardly. Accordingly, as the cam **94** is adjusted to shift ie valve spool downwardly and open the throttle, the anifold pressure increases and acts through the belows **100** to exert a progressively increasing upward orce on the valve spool. When the manifold pressure ncreases to a sufficient value that the upward force exrted on the lower end of the spool balances the downard force exerted on the upper end of the spool, the itter is moved to its centered position shown in FIG. and the throttle **37** is stopped in a position in which ie actual manifold pressure coincides with the comanded pressure. Thus, movement of the power member **40** does not cause the throttle to move to a particuar predetermined position but instead causes the throtle to move until the commanded manifold pressure is ctually established. As a result, the manifold pressure pecified for a given power level can be accurately set nd maintained.

If the cam **94** is in a given position and the altitude f the aircraft is increased, the manifold pressure decreases as a result of the decreased pressure of the air t the higher altitude. As the manifold pressure decreases, the bellows **100** expands and shifts the valve pool **89** downwardly to cause opening of the throttle 7 to obtain the proper manifold pressure. In order to chieve the recommended manifold pressure at the igher altitude, however, the throttle should not open o far as to bring the manifold pressure back up to its riginal value. Instead, the throttle should open to a poition establishing a manifold pressure slightly lower han that maintained at the lower altitude. In other ords, the throttle should be positioned to cause manifold pressure to droop at higher altitudes as indicated y the curves shown in FIG. **2.** In order to provide such droop, a bellows **105** which is open to the atmosphere s attached to the upper end portion of the valve spool 9 and is surrounded by a chamber **106** communicating vith the drain line **93** through the passage **103** and illed with fuel at drain pressure. The bellows **101** and **05** serve to seal the ends of the valve bore **90** and both re of equal area so that internal fuel pressure changes ave no effect on the position of the valve spool **89.**

As the altitude of the aircraft increases and the pressure and density of the ambient atmosphere decrease, he bellows **105** tends to contract to raise the valve pool **89.** As manifold pressure decreases, the bellows .00 tends to lower the valve spool to restore the manifold pressure to its original value but, because of the mbient pressure bias applied by the bellows **105,** the nanifold pressure droops and actually takes on a value lightly lower than its original value. The bellows **105** is of smaller area than the bellows **100** and the effect of ambient pressure on manifold pressure is proportional to the ratio of the areas. By properly sizing the bellows **100** and **105,** the manifold pressure may be made to droop substantially in accordance with the curves of FIG. **2.**

To adjust the manifold pressure automatically in response to changes in outside temperature, a cantilevered bimetallic strip **107** is shown as being sandwiched between the compression spring **96** and the upper end of the valve spool **89.** As temperature increases, the bimetallic strip flexes downwardly and applies a downward bias to the valve spool so as to open the throttle **37** and cause the manifold pressure to increase substantially in accordance with the curves shown in FIG. **3.** If temperature decreases, the bimetallic strip flexes upwardly and reduces the spring pressure on the valve spool **89.** The throttle thus closes to lower the manifold pressure.

From the foregoing, it will be apparent that the present invention brings to the art new and improved control apparatus in which a single power member **40** schedules speed and fuel flow directly as a function of the position in which the power member is set. The power member also schedules manifold pressure in accordance with speed and fuel flow while the bias applied by the pressure and temperature sensors **105** and **107** serves to trim the manifold pressure so as to establish the latter at the values specified for various altitudes and temperatures. Accordingly, the pilot may select a desired power level simply by setting the power member and, as an incident to such positioning, speed, fuel flow and manifold pressure are automatically and accurately set at the values which are recommended by the engine manufacturer to develop the desired power at a given altitude and with a given temperature.

If the power member **40** of the engine **16** is set for a given power level and the aircraft is flying at an altitude which lies to the right of the diagonal line *a* shown in FIG. **2,** the atmospheric pressure is so low that the manifold pressure needed to maintain the desired power setting cannot be obtained even if the throttle **37** is fully opened. Under these circumstances, it is desirable to reduce the fuel flow to a rate below that scheduled by the position of the power member so that the actual fuel flow will be correlated with the reduced power which is actually obtained. Such reduction in fuel flow if advantageously achieved by bypassing some of the fuel in the engine line **34** to the drain line **93** by way of a line **108** communicating between the line **34** and a port **109** in the pilot valve **87,** the port normally being closed by a land **109a** on the valve spool **89.** If the atmospheric pressure is so low that the manifold pressure commanded by the position of the power member and by the outside temperature cannot be obtained, the valve spool **89** will shift downwardly to uncover the port **109** and allow some of the fuel to bypass the engine **16** and flow to the drain line **93,** the extent of downward displacement of the spool being proportional to the difference between the commanded manifold pressure and the actual manifold pressure. As a result, even when the selected power setting cannot be obtained, a fuel mixture of the correct fuel/air ratio will be delivered to the engine to avoid the wasting of fuel and to keep the engine operating under safe conditions. The bypass of the scheduled fuel also will occur during

throttle bursts, some fuel being bled to drain until the manifold pressure reaches the new setting.

Means are provided to enable the pilot to trim the engine speed independently of the position of the power member **40** so that the pilot may maintain a given power while running the engine **16** at a speed of his own selection in order to achieve lowest noise conditions, best fuel economy and the like. Herein, these means comprise a manually adjustable speed trim member **110** whose inner end is connected to the upper end of the lever **44** by the pivot **45**. Normally, the speed trim member **110** is held in a cruise position shown in FIG. **1** by a spring-loaded detent **111** which seats in a notch **113** in the speed member. With the speed member **110** in the cruise position, the speed of the engine **16** is established in accordance with the position of the power member **40** and is scheduled with respect to power as shown by the curves of FIGS. **2** and **3**. If the pilot wishes to develop the same power while running the engine at either a slightly faster or slightly slower speed, he may adjust the speed member **110** inwardly or outwardly. As an incident to such adjustment, the lever **44** is rocked about the lower pivot **43** an acts through the link **46** to change the setting of the speed control element **26** of the governor **19**.

When the speed of the engine **16** is trimmed, it is necessary to also adjust the manifold pressure in order to maintain the power called for by the position of the power member **40**. For this purpose, a pivoted bellcrank **114** is connected between the speed trim member **110** and the upper end of an upright link **115** whose lower end is connected to a lever **116** adapted to swing upwardly and downwardly about a fixed pivot **117**. The bimetallic strip **107** is cantilevered on the inner end portion of the lever **116** and thus the force exerted on the upper end of the valve spool **89** by the compression spring **96** may be adjusted by swinging the lever upwardly and downwardly. If the pilot moves the speed member **110** inwardly to establish a speed slightly higher than dictated by the power member **40**, the valve spool **89** is lifted to cause closing of the throttle **37** and lowering of the manifold pressure. Conversely, lowering of the speed by the speed trim member **110** results in the valve spool being shifted downwardly to cause an increase in manifold pressure. Thus, with this arrangement, the manifold pressure is adjusted at the same time engine speed is trimmed so that the engine still will develop the power specified by the setting of the power member **40**.

The speed trim member also is used to enable the pilot to override the pilot valve **87** and manually control the throttle **37** in a direct manner if the bellows **100** and **105** should malfunction or if some other failure should occur in the control apparatus. As shown, a finger **120** is carried on the inner end of the lever **116** and underlies the upper end of the valve spool **89**. When the pilot pushes the speed member **110** inwardly sufficiently far to seat the detent **111** into an override notch **121**, the finger **120** is swung upwardly and lifts the valve spool **89** so as to port the left side of the throttle servo **80** to drain. Under this condition, the spring **86** shifts the throttle piston **81** to the left until the throttle linkage **84** stops against a screw **123**. The latter is adjustably threaded into a plate **124** connected to an arm **125** which, in turn, is carried on the shaft **50**. When the pilot valve **87** is overridden, the pilot may directly move the throttle **37** by adjusting the power member **40** to turn the shaft **50** and cause the screw **123** to shift the throttle linkage **84** and change the throttle setting. In order to permit the throttle to be opened under direct manual control, the linkage **84** is attached to the throttle piston **81** by a yieldable connection indicated generally by the reference numeral **126** and having a spring **126***a* enabling the linkage to move relative to the piston when manually adjusted, the spring **126***a* also serving to bias the linkage against the screw **123**. The adjusted position of the screw **123** determines the position of the throttle **37** at idle speed while fuel flow to the engine **16** at idle speed is determined by the position of a second adjustable screw **127** adapted to engage the plate **124** and limit the extent to which the power member **40** may be pulled outwardly.

Another embodiment of a control apparatus is shown in FIG. **4** in which parts corresponding to those of the first embodiment are indicated by the same but primed reference numerals. In this instance, the member **110'** is not used to trim the speed of the engine **16'** during flight but instead is used to purge the prop servo **20'** of cold oil when the engine is first started on the ground during cold weather. By pulling outwardly on the member **110'** against the bias of a spring **130**, the speed setting of the governor **19'** may be reduced to such a value that all of the cold oil in the prop servo is dumped therefrom through the governor valve associated with the rod **24'**. The member **110'** then may be released inwardly to its position shown in FIG. **4** so as to increase the speed setting of the governor **16'** and deliver warm oil to the prop servo **20'**. It will be noted that movement of the member **110'** has no effect on the position of the pilot valve spool **89'** since the control apparatus shown in FIG. **4** does not include a linkage corresponding to the linkage **114**, **115** and **116** of the control apparatus shown in FIG. **1**. Accordingly, the member **110'** may change the speed setting of the governor **16'** without changing the setting of the pilot valve spool **89'**.

Like the control apparatus of the first embodiment, the control apparatus shown in FIG. **4** includes a mixture control member **65'** which may be used to cut off the fuel flow and to richen or lean the fuel-air mixture manually. The mixture control member **65'**, however, is moved from its normal cruise position shown in FIG. **4** only when special conditions dictate that the fuel-air mixture should be made richer or leaner. During take off and climb, an enrichment orifice **131** in the metering valve **35'** automatically richens up the mixture to provide for additional cooling of the engine. Accordingly, it is not necessary to move the mixture control member **65'** during normal take off and climb.

In the control apparatus shown in FIG. **4**, the bellows **100'** is located directly in the manifold **36'** and is filled with a gas such as helium. When the temperature of the air in the manifold **36'** increases, the gas expands the bellows **100'** to shift the pilot valve spool **89'** downwardly and cause the throttle **37'** to open and increase the manifold pressure. The bellows **100'** thus is responsive not only to the pressure but also the temperature of the air in the manifold so as to provide a comparatively accurate reflection of the temperature of the air entering the cylinders of the engine **16'**.

A further difference between the control apparatus shown in FIG. **1** and that shown in FIG. **4** resides in the manner of positioning the throttle **37'**. In the control apparatus shown in FIG. **4**, the throttle is set directly by the power lever **40'** and then is trimmed by the throttle

servo **80'** in accordance with manifold pressure, ambient pressure and temperature. As shown, a linkage **140** is connected directly to the shaft **50'** and also is connected at **141** to a differential lever **143.** The latter is pivoted intermediate its ends at **144** and is connected at its lower end to a linkage **145** which is connected to the throttle **37'**. When the shaft **50'** is rotated clockwise by inward movement of the power member **40'**, the linkages **140** and **145** and the lever **143** cause the throttle to open.

If the position of the throttle **37'** as set by the shaft **50** does not establish the manifold pressure commanded by the cam **94'** and by ambient pressure and temperature, the pilot valve spool **89** is displaced and causes the throttle servo **80'** to adjust or trim the throttle until the commanded manifold pressure is reached. For this purpose, a link **146** is connected to the servo piston **81'** and its outer end defines the intermediate pivot **144** for the differential lever **143.** When the piston **81'** is shifted by displacement of the valve spool **89'**, the link **146** causes the lever **143** to swing about the upper pivot **141** and adjust the throttle until the actual manifold pressure corresponds with the commanded value.

I claim as my invention:

1. Control apparatus for an internal combustion engine connected to drive a variable pitch propeller, said engine having:

a. a governor adjustable to different speed settings and operable to vary the pitch of the propeller to maintain the actual speed of the engine substantially in agreement with a set speed,

b. a fuel valve adjustable to different positions to regulate the rate of flow of fuel to the engine, and

c. a throttle adapted to be set in different positions to regulate the flow of combustion air to the engine and to adjust the manifold pressure of the engine,

said control apparatus including:

a. a speed control element which is operable when moved to change the speed setting of said governor,

b. a fuel control element which is operable when moved to change the position of said fuel valve, and

c. a throttle control element which is movable to different positions,

said control apparatus further including:

a. a control member connected to all three of said elements and operable to move all three elements in response to being manually adjusted, thereby to correlate the speed of said engine with the rate of fuel flow and to set said throttle control element in a position correlated both with engine speed and rate of fuel flow,

b. first means for sensing variations in the density of the ambient atmosphere,

c. second means for sensing variations in the manifold pressure of said engine,

d. third means responsive to said first and second means and to the position of said throttle control element and operable to automatically move said throttle in response to variations in the density of the ambient atmosphere and/or the manifold pressure of said engine and/or in response to movement of said throttle control element and operable to locate said throttle in a position causing the manifold pressure to be correlated with the density of the ambient atmosphere and the position of the throttle control element, and

e. means causing said fuel to flow past said fuel valve with a predetermined constant pressure drop whereby the flow rate of said fuel past said valve is directly proportional to the position of said valve, said last-mentioned means being selectively adjustable to cause said fuel to flow past said valve with a different constant pressure drop whereby the flow rate of the fuel may be changed without changing the position of said valve, and a second control member connected to said last-mentioned means and operable to adjust the latter in response to being manually moved.

2. Control apparatus as defined in claim **1** in which said first means includes pressure-responsive means for sensing variations in the pressure of the ambient atmosphere.

3. Control apparatus as defined in claim **2** in which said pressure-responsive means cause said throttle to close when the density of the ambient atmosphere decreases as a result of a decrease in the pressure of the ambient atmosphere and in which said second means cause said throttle to open when manifold pressure decreases as a result of a decrease in the pressure of the ambient atmosphere, said pressure-responsive means and said second means being correlated with one another so the resultant effect of a given decrease in ambient pressure causes opening of said throttle but by a lesser amount than would be the case in the absence of said pressureresponsive means.

4. Control apparatus as defined in claim **1** in which said first means includes temperature-responsive means for sensing variations in the temperature of the ambient atmosphere and for causing said throttle to open when the temperature of the ambient atmosphere increases.

5. Control apparatus as defined in claim **1** in which said first means includes pressure-responsive means for sensing variations in the pressure of the ambient atmosphere and further includes temperature-responsive means for sensing variations in the temperature of the ambient atmosphere.

6. Control apparatus for an internal combustion engine connected to drive a variable pitch propeller, said engine having:

a. a governor adjustable to different speed settings and operable to vary the pitch of the propeller to maintain the actual speed of the engine substantially in agreement with a set speed,

b. a fuel valve adjustable to different positions to regulate the rate of flow of fuel to the engine, and

c. a throttle adapted to be set in different positions to regulate the flow of combustion air to the engine and to adjust the manifold pressure of the engine,

said control apparatus including:

a. a speed control element which is operable when moved to change the speed setting of said governor,

b. a fuel control element which is operable when moved to change the position of said fuel valve, and

c. a throttle control element which is movable to different positions,

said control apparatus further including:

a. a control member connected to all three of said elements and operable to move all three elements in

response to being manually adjusted, thereby to correlate the speed of said engine with the rate of fuel flow and to set said throttle control element in a position correlated both with engine speed and rate of fuel flow,

b. first means for sensing variations in the density of the ambient atmosphere,

c. second means for sensing variations in the manifold pressure of said engine,

d. third means responsive to said first and second means and to the position of said throttle control element and operable to automatically move said throttle in response to variations in the density of the ambient atmosphere and/or the manifold pressure of said engine and/or in response to movement of said throttle control element and operable to locate said throttle in a position causing the manifold pressure to be correlated with the density of the ambient atmosphere and the position of the throttle control element, and

e. means for automatically bypassing fuel away from said engine when manifold pressure drops to a predetermined level.

7. Control apparatus for an internal combustion engine connected to drive a variable pitch propeller, said engine having:

a. a governor adjustable to different speed settings and operable to vary the pitch of the propeller to maintain the actual speed of the engine substantially in agreement with a set speed,

b. a fuel valve adjustable to different positions to regulate the rate of flow of fuel to the engine, and

c. a throttle adapted to be set in different positions to regulate the flow of combustion air to the engine and to adjust the manifold pressure of the engine,

said control apparatus including:

a. a speed control element which is operable when moved to change the speed setting of said governor,

b. a fuel control element which is operable when moved to change the position of said fuel valve, and

c. a throttle control element which is movable to different positions,

said control apparatus further including:

a. a control member connected to all three of said elements and operable to move all three elements in response to being manually adjusted, thereby to correlate the speed of said engine with the rate of fuel flow and to set said throttle control element in a position correlated both with engine speed and rate of fuel flow,

b. first means for sensing variations in the density of the ambient atmosphere,

c. second means for sensing variations in the manifold pressure of said engine,

d. third means responsive to said first and second means and to the position of said throttle control element and operable to automatically move said throttle in response to variations in the density of the ambient atmosphere and/or the manifold pressure of said engine and/or in response to movement of said throttle control element and operable to locate said throttle in a position causing the manifold pressure to be correlated with the density of the ambient atmosphere and the position of the throttle control element, and

e. a second control member connected to said speed control element and operable when adjusted manually to move said speed control element without moving said fuel control element whereby engine speed may be changed without changing the rate of fuel flow, and means responsive to movement of said second control member and coacting with said third means to adjust the position of said throttle when said second control member is moved.

8. Control apparatus as defined in claim **7** further including means connected to said second control member and operable to disable said third means when said second control member is moved to a predetermined position.

9. Control apparatus as defined by claim **8** further including means movable by said first control member and operable to move said throttle when said third means are disabled and said first control member is moved.

10. Control apparatus as defined in claim **7** further including means causing said fuel to flow past said fuel valve with a predetermined constant pressure drop whereby the flow rate of said fuel is directly proportional to the position of said valve, said lastmentioned means being selectively adjustable to cause said fuel to flow past said valve with a different constant pressure drop whereby the flow rate of the fuel may be changed without changing the position of said valve, and a third control member connected to said last mentioned means and operable to adjust the latter in response to being manually moved.

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