Aug. 12, 1958 F. C. MOCK 2,846,846

FUEL SYSTEM FOR GAS TURBINE ENGINES HAVING MEANS FOR AVOIDING COMPRESSOR INSTABILITY

Filed June 14, 1951 3 Sheets-Sheet 1

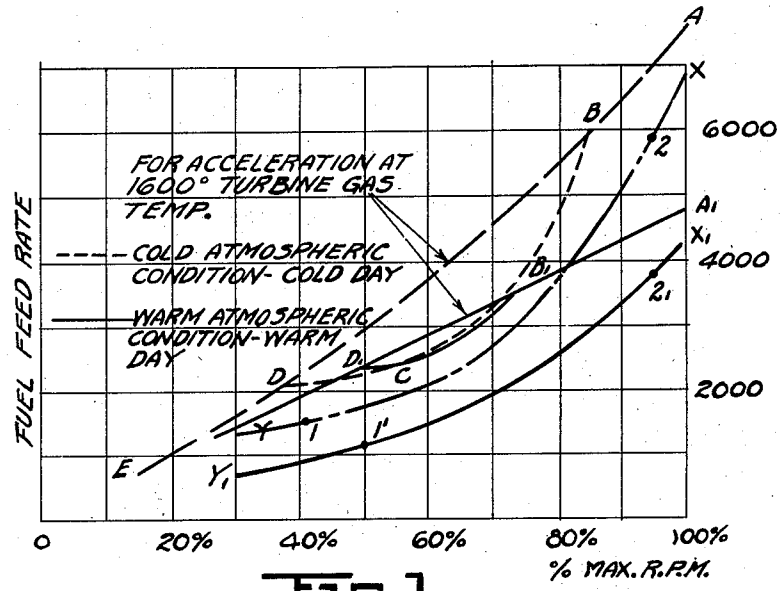

FIG. 1

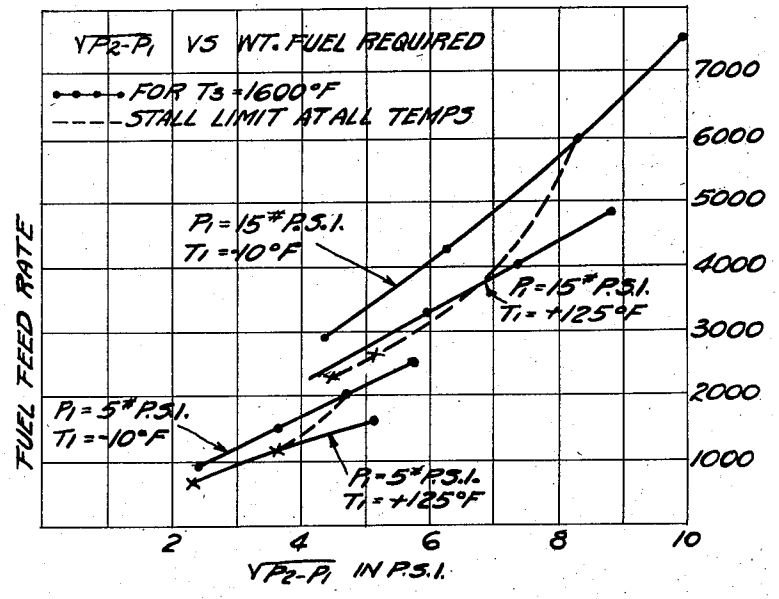

FIG. 2

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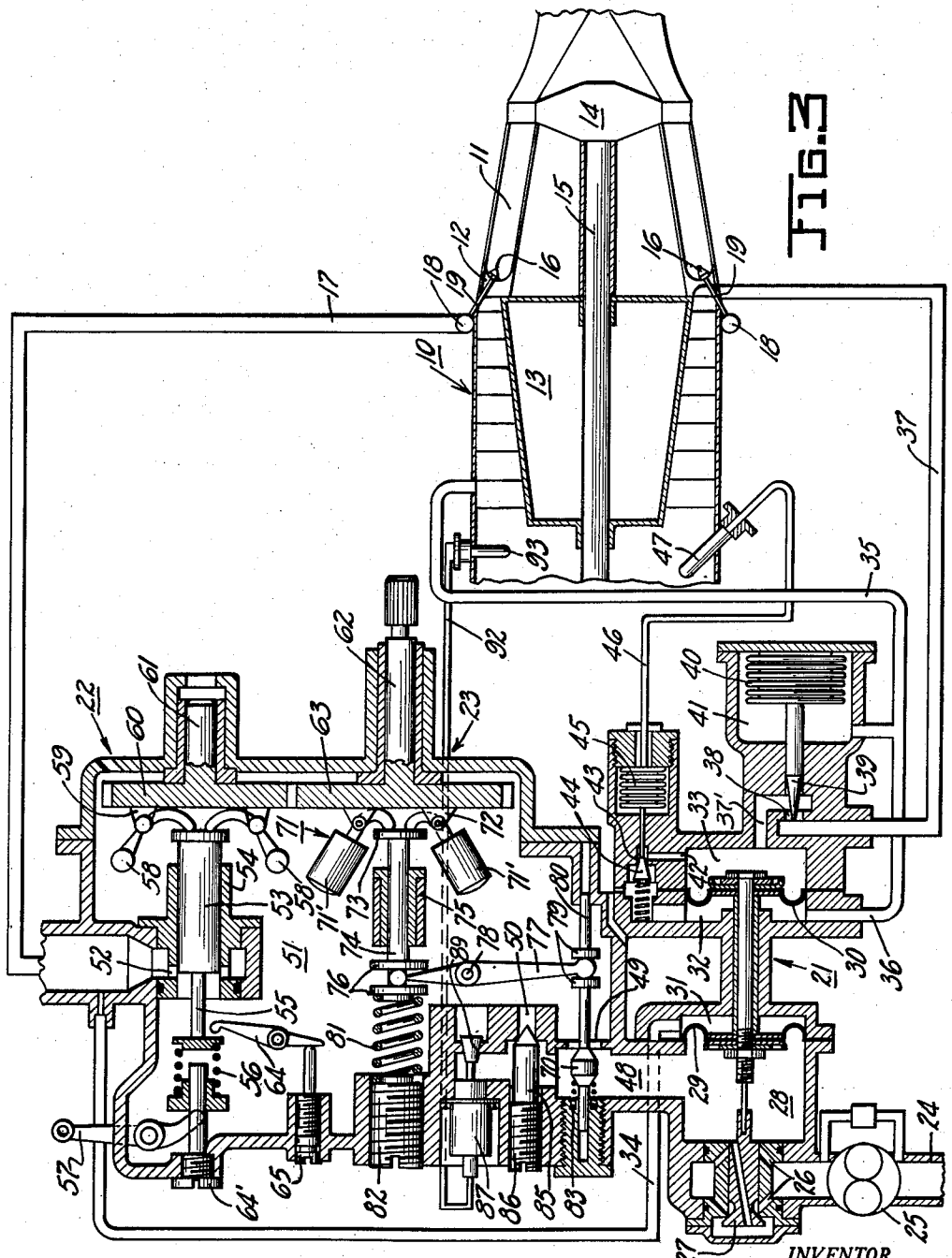
FIG. 2



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Filed June 14, 1951 3 Sheets-Sheet 3

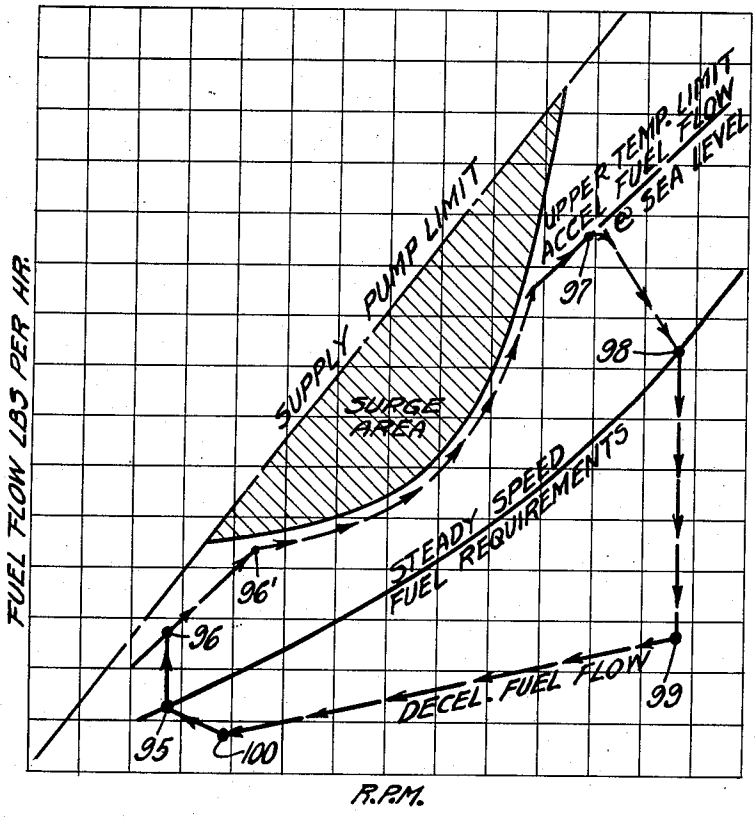

FIG. 4

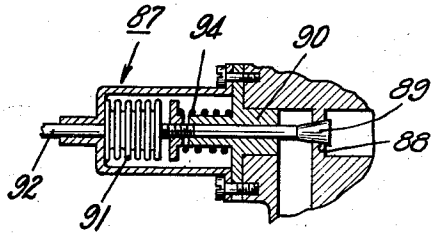

FIG. 3A

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2,846,846

FUEL SYSTEM FOR GAS TURBINE ENGINES HAVING MEANS FOR AVOIDING COMPRESSOR INSTABILITY

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Application June 14, 1951, Serial No. 231,556

16 Claims. (Cl. 60—39.28)

This invention relates to a fuel feed and power control system for gas turbine engines; more particularly for gas turbine engines adapted for the propulsion of aircraft, such as what are now commonly known as turbojet and turboprop engines.

It is, of course, highly desirable that a pilot or operator of a turbojet or turboprop engine be free to accelerate rapidly and smoothly at all altitudes simply by resetting a control lever or member to a selected power position without worrying about, or danger of, (*a*) exceeding the upper temperature limit for that particular engine, (*b*) causing flame blow-out in the burner or burners, or (*c*) producing surge or compressor stall, and which latter in a turboprop engine may also occur as a result of decreasing speed upon application of an external load. Another transitional hazard that should be mentioned is flame-out or burner die-out upon deceleration or sudden closure of the throttle and reduction in fuel feed at high engine speed.

With a dynamic air compressor running at a given speed and delivering through an orifice of fixed size, the air weight delivery tends to vary as the entering pressure and inversely as the entering temperature. If the air be raised in temperature after leaving the compressor but before reaching the discharge orifice, this will in general cause the weight delivery to decrease and the delivery pressure to rise, up to a point where the compressor stalls. If, however, the delivery conditions be such that the velocity of flow through the orifice approximates that of sound, as indicated or defined by the absolute temperature of the air approaching the orifice, this absolutely limits the weight flow through the orifice; the velocity varies with the square root of the absolute temperature, and the density inversely as the absolute temperature (and directly with the pressure), so that the net weight flow varies with the square root of the absolute temperature.

This latter is generally the case with a gas turbine in the maximum power range. The velocity is sonic through the nozzles through which the gas enters the turbine blades; the weight flow varies with the square root of the entering gas temperature and directly with its pressure; and all this is only remotely connected with the temperature entering the compressor.

If the weight of air passed by the turbine under the condition of maximum turbine gas temperature, which is as above stated practically independent of entering air temperature, is in excess of that quantity which the compressor could deliver at the same pressure (note that this last quantity does vary with entering air temperature), the turbine gas temperature dictates the maximum amount of fuel which can be fed. But if raising the turbine gas temperature to the maximum indicated by turbine endurance causes the compressor to stall, then lower combustion temperature, lower fuel flow, and lower thrust must be tolerated. Obviously, the engine design must be such as to permit the engine to run at steady

speed without compressor stall; and the loss in performance imposed by compressor stall characteristics is usually confined to slower acceleration in the mid-speed range.

In illustration of the foregoing, the fuel feed requirements of a given axial compressor type turbojet engine in the higher compression ratios at constant entering air pressure (given altitude) but at varying or two different entering air temperatures are assumed to be as plotted in the curve chart of Figure 1, where the full lines represent the requirements for a warm entering air temperature, say in the neighborhood of +125° F., and the dotted lines a cold entering air temperature, for instance −10° F. Here the lines EA, EA_1 indicate the maximum rate of fuel feed to be observed in order to keep within a safe upper turbine temperature limit, and they also indicate a trend which will avoid "blow-out," particularly at altitude. The curved lines DB and D_1B_1 define the surge area; they indicate the rate of fuel feed to be observed to avoid surge, or the upper limit on the rate of fuel feed as determined by the surge characteristic of that particular engine. The curves YX and Y_1X_1 represent the rates of fuel feed required to maintain a steady speed; with an all-speed governor type throttle valve they represent fixed throttle settings at an equilibrium or balanced condition with respect to the rate of fuel feed and engine speed.

In Figure 2 an attempt is made to approximate the quantity of fuel required to maintain a 1600° F. turbine inlet temperature for four different sets of entering air pressure and temperature values showing the relationship of fuel feed rate to compressor rise.

The relations of required fuel flow, engine speed, entering air and turbine gas temperatures, combustion efficiency, and compressor stall are both mathematically complex in theory and functionally irregular in practice. I have found, however, that the following more or less empirical relations give a close enough approximation to permit an improved and practical scheme of control. In the following, the symbols P_1 and T_1 designate, respectively, the pressure and temperature of the air entering the compressor; P_2, the pressure just beyond the compressor; and T_3, the temperature of the gas entering the turbine. Note that the limiting values of fuel feed given vary according to the consecutive listed conditions of engine operation:

(1) With a given absolute safe value of T_3, turbine gas temperature, the amount of fuel that can be tolerated per pound of air will decrease with increase of T_1, entering air temperature, or with increase of compression temperature. I have found that to hold a given maximum turbine gas temperature under changes of entering air temperature and pressure, the fuel feed should vary generally as

$$\frac{\sqrt{P_1}\sqrt{P_2-P_1}}{T_1}$$

(2) In the compressor stall range, I have found that the permissible maximum amount of fuel may be considered as an empirical curve based upon $\sqrt{P_1}\sqrt{P_2-P_1}$; and is to a considerable extent independent of the entering air temperature. On the other hand, the point of occurrence of the stall range at different entering pressures follows the engine speed so closely that this engine speed, with perhaps minor modification by temperature, may be used as a signal for beginning the curve deviation.

(3) The change of fuel feed required to give a certain maximum engine speed under change of entering air pressure and temperature lies between (1) and (2) above. But when a governor is used to determine maximum speed, as in the invention here described, no particular correction is needed provided the maximum scheduled

fuel feed is in excess of that required for steady operation at maximum speed. While compressor pressure rise has previously been proposed as a means of fuel metering, it is believed that the exponential values of pressure and temperature compensation, as herein set forth, are novel, distinctive and valuable in the art. The mechanical adaptation shown also presents the advantage of being straightforward, simple and capable of rather general application with minor change. Another novel element of the invention is a so-called "stall modulator construction" by a variable orifice in series with the main governor metering orifice. This provides both automatic temperature compensation for the stall range and also forms a manual adjustment for minor variations between engines of the same model. Its action is also simple and straightforward.

In the drawings:

Figures 1 and 2 are curve charts for supplementing the brief analysis of the theory on which the invention is based;

Figure 3 illustrates schematically one form of fuel feed and power control device capable of functioning in accordance with the invention;

Figure 3A is an enlarged longitudinal section of a temperature compensating control valve; and

Figure 4 is a performance curve for an engine equipped with the improved control.

Referring to Figure 3 in detail, a gas turbine engine is generally indicated at **10** which includes a series of combustion chambers **11**, mounted in a casing having a header or air intake section **12**. A dynamic compressor is indicated at **13** and is shown as of the axial flow type driven by means of a turbine **14** through a shaft **15**. Each of the combustion chambers is provided with a burner nozzle **16** to which metered fuel is supplied under pressure by way of a conduit **17**, fuel manifold **18**, and individual fuel lines **19**, in a manner to be described.

The parts which go to make up the fuel metering and power control system may be classified generally as a metering head regulator section **21**, governor section **22**, and stall modulator section **23**.

Fuel from a suitable source of supply, such as a fuel tank, not shown, flows to the regulator through inlet conduit **24**, having a suitable pressurizing device therein, such as a pump **25** of the by-pass type which maintains the supply at a substantially constant pressure. From conduit **24** the fuel flows through ports **26** and across regulator valve **27** to chamber **28**. Valve **27** is preferably of the balanced type and is controlled by a double or dual regulator comprising a pair of diaphragms **29** and **30**, the diaphragm **29** constituting a movable wall between expansible chambers **28** and **31** and the diaphragm **30** a like wall between expansible chambers **32** and **33**. Chamber **31** is vented to metered fuel pressure by way of passage **34**, chamber **32** to compressor inlet or P_1 pressure by way of passages **35** and **36**, and chamber **33** to compressor outlet or P_2 by way of passage **37**, variable orifice **38** and passage **37'**. The area of orifice **38** is controlled by a contoured needle valve **39**, carried by the movable end of a pressure responsive bellows **40**, mounted in a chamber **41**, which is vented to compressor inlet or P_1 pressure by way of passage **35**. Between chambers **33** and **32** is a passage **42**, having therein a variable orifice **43**, the area of which is controlled by a contoured needle valve **44**, carried by the movable end of a temperature responsive bellows **45** connected by capillary tube **46** with a temperature bulb **47**, located to sense compressor inlet or entering air (T_1) temperature.

As will be more fully explained in the description of operation, the effective flow position of the regulator valve **27** and hence the metering head between chamber **28** and fuel conduit **17** is determined by the differentials across diaphragms **29** and **30**. The forces (pressure difference times area) at a given pressure drop between chamber **28** and metered fuel conduit **17** and at a given compressor rise and entering air pressure and temperature, will be equal and opposite, or their sum total will be zero, and balanced valve **27** will remain at a given flow position; but should there be a change in any of these variables and hence in any one of both of the said differentials, the regulator will become unbalanced and valve **27** will be repositioned to increase or decrease the pressure in chamber **28** until a balanced condition is again established. Since the flow through a metering orifice tends to vary as the square root of the metering head, the quantity of fuel metered to the engine will be proportionate to the square root of the compressor rise modified by entering air pressure and temperature.

From chamber **28**, fuel flows to the outlet conduit **17** through passage **48**, either one or both orifices **49** and **50**, chamber **51** and metering orifice **52**.

The area of the metering orifice **52** is controlled by an all-speed governor valve **53**, which is preferably of the balanced type and is slidably mounted in a seat or sleeve **54**. The valve **53** is provided with a headed stem **55** engaged by a governor spring **56** adapted to be variably tensioned by a lever **57** which constitutes a power control member (or may be connected to such member), said spring tending to open the valve **53** against the balancing force of governor weights **58**, pivotally mounted on brackets **59**, carried by rotatable gear **60**, formed on the inner end of a shaft **61**. The gear **60** is driven in relation to engine speed from a shaft **62** and gear **63**. The maximum opening travel of governor valve **53** is determined by a stop **64** externally adjustable by means of screw **65**, while its minimum closing travel may be determined by adjustable guide rod **64'**.

To select a desired engine speed, the pilot or power control lever **57** is reset to a position which will subject governor spring **56** to a given compression or tensioning action which will unbalance the then existing equilibrium condition of the governor weights **58** with respect to the governor spring, whereupon the throttle or governor valve **53** will either open or close to increase or decrease flow of fuel to the engine and the speed of the latter will either increase or decrease until an equilibrium condition is again attained as determined by the setting of the pilot's control lever. Also, at a given setting of the pilot's control lever, should be the speed of the engine tend to vary from the selected speed, the governor will become unbalanced, whereupon the governor weights will automatically adjust valve **53** to return the engine speed to the selected value, as is well understood by those having a knowledge of the art. Should the pilot reset his control lever to accelerate to full power from a low or intermediate power setting, valve **53** would open to a maximum as determined by stop **64** and the engine would accelerate to maximum governed speed with the rate of fuel feed at each point of transition determined by the metering area of orifice **52** and the fuel or metering head across said orifice. As heretofore noted, the metering head across orifice **52** is a function of compressor rise and entering air pressure and temperature; and it is further subject to modification during part of the speed range by the stall modulator system in section **23**, to obtain the dip BCD or B_1CD_1 in Figure 1.

Referring to the modulator section **23** of Figure 3, the variable orifice **49** is regulated by a contoured valve **70** which is positioned automatically as a function of engine speed by a speed-sensing element generally indicated at **71** and comprising centrifugal weights **71'** which are pivotally mounted on brackets **72** carried by the gear **63** and having inner fingers or shoes engaging a collar or bearing surface **73** on the adjacent end of a shaft or rod **74**, said rod being slidably mounted in a bushing **75** and having its opposite end provided with spaced collars **76** between which the adjacent or upper forked end of a lever **77** engages. The lever **77** is pivotally mounted or fulcrumed at **78** and at its opposite or lower forked end engages a pair of spaced collars or bosses **79** formed on

the stem **80** of valve **70**. A calibrated spring **81** acts counter to the centrifugal weights **71'** of governor **71** and is externally adjustable by means of a screw **82**. For engines having different compressor stall characteristics, the spring **81** may be adjusted as desired to preset governor **71** so that the engine speed at which the stall dip deviation from the line AE, A_1E is initiated, is as required. A light stabilizing spring **83** may be provided for the valve **70**.

It has been found that on different engines of the same model or design (and supposedly having the same operational characteristics) the magnitude of the stall dip or curve BCD, B_1CD_1 with respect to fuel requirements may be different, while the respective speeds at which deviation from the line AE, A_1E takes place or is required may not change. A convenient adjustment for adapting the control to such variations is provided by the contoured valve **85**, which regulates the area of the orifice **50** and is externally adjustable by screw **86**.

As will be more fully explained in the description of operation, at some predetermined point in the mid-speed range of the engine, depending upon the setting of governor **71** by spring **81** and/or the contour of valve **70**, the latter becomes effective to reduce the metering head across the governor valve **53**; and by predetermining the fixed area of orifice **50** with respect to variable parallel orifice **49**, the magnitude of curves BCD or B_1CD_1 may be varied without varying the point of departure (speed function) from lines AE or A_1E. This results from the fact that the magnitude of the stall fuel head varies as the total combined area of the orifices **49** and **50**, while the particular engine speed at which the stall head starts depends upon the beginning of the restricting action by valve **70**. In this connection it will be understood that the total or combined area of parallel orifices **49** and **50** is substantially in excess of the area of the metering orifice **52**.

The temperature modifying action on the fuel head by valve **44** is proportionately effective throughout the range of engine speed, but such modification in the mid-speed range may constitute a variable; usually less temperature modification in the surge area or mid-speed range being required. This compensation is provided for by the valve unit or assembly generally indicated at **87**, which may be used in conjunction with or substituted for the valve **85**. An orfice **88**, Figure 3A, in parallel with orifice **49** and/or orifice **50**, is regulated by a valve **89** having its stem slidable in bushing **90** and connected to the free or movable end of a bellows **91**, in fluid communication by way of capillary tube **92** with a temperature bulb **93**, so located as to sense compressor or engine inlet temperature, the bellows, tube and bulb being loaded with a suitable temperature responsive fluid or gas. A spring **94** tends to urge valve **89** to closed position.

It may be assumed that the control is set or calibrated for a relatively warm atmospheric condition at sea level (warm day), then should the entering air become appreciably colder, bellows **45** will shrink and produce an increase in the metering head across orifice **52**. Simultaneously, however, the bellows **91** shrinks and valve **89** reduces the area of orifice **88**, thereby reducing the total flow area provided by parallel orifices **49** and **88** and proportionally reducing the metering head across orifice **52**. By properly contouring valves **70** and **89**, the compensating action may be restricted to the stall range. It will be noted that the contour of valve **70** is such that at the upper and lower ends of the speed range BA and ED, the area of orifice **49** is so great as to constitute no appreciable restriction to fuel flow, so that the position of valve **89** at this time has little effect on the metering head.

Operation

In the respective positions of the various parts as shown in Figure 3, the engine may be assumed to be operating

at a steady speed in the low speed range, say at point **95** in Figure 4. If now the pilot desires to accelerate from **95** to **98**, lever **57** would be rotated counterclockwise and governor valve **53** opened to the limit determined by stop **64**. The suddenly increased metering area of orifice **52** would result in a sharp increase of the rate of fuel feed to, for example, point **96**, but at this point the metering head takes effect and causes fuel flow to follow the arrows to point **97** where the all-speed governor begins to cut off fuel and flow decreases to point **98**.

When the throttle is suddenly opened, there is a momentary drop in pressure in chamber **28** and the decreased differential across diaphragm **29** will tend to open the regulator valve **27**. The extent to which this valve opens, however, is also controlled by the relative pressures in chambers **32** and **33**, or the differential across diaphragm **30**, which is a function of compressor rise and compressor inlet pressure and temperature. As the speed of the engine begins to increase and the rise across the compressor increases, the differential across diaphragm **30** acts in a direction to open the regulator valve **27**, but this opening travel and hence the increase in metering head is proportional to compressor rise modified by inlet pressure and temperature, and hence the rate of fuel feed is maintained within a predetermined upper limit and follows the arrows from **96** to **96'** in Figure 4. At this point the stall modulator governor **71** has moved valve **70** to the right to where it begins to restrict orifice **49** and reduce the fuel metering head across valve **53**, whereupon the rate of fuel feed is reduced to avoid the surge area. At the lowest point in the surge dip, the maximum diameter of valve **70** is interposing a maximum restriction to flow through orifice **49**, and as said valve moves further to the right, flow through said orifice, and hence the metering head across valve **53**, gradually increases to where the rate of fuel feed again reaches the upper limit for acceleration as it passes the surge area, at which time valve **70** will have opened orifice **49** to its maximum area or to where it has no appreciable effect on said metering head. As acceleration continues along the upper temperature limit, the metering head again becomes solely a function of compressor rise, modified by compressor inlet pressure and temperature. At point **97**, the speed of the engine has substantially attained the selected value, or to where the all-speed governor weights **58** are substantially in balance with the setting of the governor spring **56**, whereupon the rate of fuel feed decreases to the point **98** along the steady speed curve.

Should the pilot wish to decelerate from point **98** back to point **95**, power control lever **57** is rotated clockwise, thereby relieving the tension on governor spring **56**, whereupon the governor weights **58** close valve **53** to where it is brought up against the adjacent end of guide rod **64'**, and the rate of fuel feed decreases sharply to point **99**, whereupon the metering head takes effect and the rate of fuel feed gradually reduces along with the compressor rise, until at point **100** the all-speed governor weights **58** are substantially in balance with the setting of the governor spring **56**, whereupon fuel feed increases slightly to point **95** along the steady speed curve.

An attempt to briefly explain the operation of the regulator **21** follows:

First considering the fuel or hydraulic section comprising chambers **28** and **31** and diaphragm **29**, it will be seen that at a given or fixed area of the metering restriction **52** and a given drop from chamber **28** to metered fuel conduit **17**, the pressure differential between chambers **28** and **31**, or between passage **48** and conduit **17**, equals or is proportional to the compensated pressure differential across diaphragm **30**. Should the metering area of either orifice **49** or **52** be increased or decreased, there will be a momentary increase or decrease in pressure in chamber **28**, whereupon valve **27** will open or close to a new position where fuel flow compensates for the change in drop across orifice **49** or **52**, at which position the

differential across diaphragm **29** again equals the differential across diaphragm **30**.

Considering now the compressor rise or air section of the regulator, comprising the chambers **32** and **33** and diaphragm **30**, here the differential across the diaphragm **30** may be considered the prime controlling factor of the regulator since any change therein will operate to modify the differential across diaphragm **29** at any engine operating condition. Without the pressure bellows **40** and temperature bellows **45** and associated circuits, the differential across diaphragm **30** would be proportional to compressor rise only, P_2-P_1, but said latter differential is biased with respect to the differential across the compressor by the variable leak pressure and temperature orifices **38** and **43**, so that any change in these parameters operates to modify the differential across the diaphragm **30**. Thus, the differential across diaphragm 30, and hence also across diaphragm **29**, varies with variations in P_2 minus P_1 and with P_1 divided by T_1, as does also the metering head; and since the flow across the metering orifice **52** tends to vary as the square root of the metering head, the quantity of fuel metered to the engine becomes proportional to the square root of P_1 times the square root of P_2-P_1 divided by T_1. Along the surge dip, the fuel feed rate is further modified as a function of engine speed by valve **85** and/or as a function of T_1 by the temperature compensating valve **89**, as heretofore explained.

In Figure 4, a sea level condition as regards altitude is assumed. As altitude is gained, pressure compensation for the rate of fuel feed is had by the aneroid bellows **40**, which acts to reduce the differential across regulator diaphragm **30** upon a decrease in pressure so that the respective curves of Figure 4 would swing downwardly until critical altitude for the particular aircraft is attained.

Although only one physical embodiment of the invention has been schematically illustrated and described, such disclosure obviously constitutes a teaching which will readily enable those skilled in the art to practice the invention and to make the required changes in form and relative arrangement of parts to adapt the improved control to engines having different characteristics.

I claim:

1. In a system for controlling the rate of fuel feed to a gas turbine engine having a compressor, means for metering fuel to the engine at a rate proportional to

$$\frac{\sqrt{P_2-P_1}}{T_1}$$

times a function of P_1 with an exponent between 1 and ½ where P_1 represents compressor inlet pressure, P_2 compressor discharge pressure, and T_1 compressor inlet temperature, and means for modifying the effects of compressor inlet temperature on the rate of fuel feed in the intermediate speed range of the engine.

2. In a system for controlling the rate of fuel feed to a gas turbine engine having a compressor, means for varying fuel flow to the engine as a function of compressor rise modified by the temperature of the air flowing to the compresor, and compressor stall control means in flow controlling relation with said first mentioned means and responsive to an engine operating condition related to power output for substantially varying the normal rate of change of fuel feed controlled by said first mentioned means at a predetermined engine speed during an acceleration of the engine in such a manner that compressor instability is avoided.

3. A system as claimed in claim 2 plus means operatively connected to said last mentioned means for varying the engine speed at which said variation in normal fuel feed rate occurs.

4. In a system for controlling the rate of fuel feed to a gas turbine engine having a compressor, adjustable governor means for maintaining a selected engine speed, control means for adjusting said governor means adapted to be reset to different positions to select an engine operating speed, means operable automatically as a function of compressor rise to maintain the rate of fuel feed within predetermined limits during a transition of engine speed and means responsive to engine speed for automatically modifying the rate of fuel feed controlled by said latter means during an acceleration of the engine.

5. A system for controlling the rate of fuel feed to a gas turbine engine having a compressor, adjustable governor means for maintaining a selected engine speed, means in flow controlling relation with said governor means and operable automatically as a function of compressor rise modified by compressor inlet temperature to maintain the rate of fuel feed within predetermined limits during a transition of engine speed, means in flow controlling relation with said last mentioned means for automatically modifying the rate of fuel feed as a function of engine speed during an acceleration of the engine, and means for automatically reducing the effects of compressor inlet temperature compensation during acceleration of the engine, whereby the engine may be accelerated without encountering compressor instability.

6. In a system for controlling the rate of fuel feed to a gas turbine engine having a compressor, the combination of a fuel metering valve, means responsive to a pressure generated by the compressor for controlling the fuel metering head across said metering valve, means responsive to a variable quantity related to power output of said engine for automatically modifying said fuel metering head during an acceleration of the engine to avoid compressor instability, and means responsive to the temperature of the air flowing to the compressor for modifying the pressure to which said fuel metering head controlling means responds.

7. In a system for controlling the rate of fuel feed to a gas turbine engine having a compressor, a metering valve, means for selectively positioning said valve to control the metering area, a regulator valve for controlling the fuel metering head across said metering area, means for automatically positioning said regulator valve as a function of compressor rise modified by compressor inlet pressure, and means responsive to changes in engine speed for automatically modifying said fuel metering head at a preselected point in the midspeed range of the engine to avoid compressor instability.

8. In a system for controlling the rate of fuel feed to a gas turbine engine having a compressor, a fuel conduit having a metering orifice therein, means for varying the area of said orifice to select an engine speed, a regulator valve in said conduit in series with said metering orifice for controlling the metering head across said orifice, pressure responsive means connected to said regulator valve, means for subjecting said pressure responsive means to compressor pressure rise modified by compressor inlet pressure and temperature, a compressor stall modulator valve also in series with said metering orifice and movable to different positions to modify the metering head, engine speed responsive means for controlling said latter valve, another valve in parallel with said stall modulator valve, and means responsive to changes in compressor inlet temperature for controlling said latter valve, whereby fuel flow to the engine is controlled during an acceleration thereof to avoid compressor stall.

9. In a system for controlling the rate of fuel feed to a gas turbine engine having a compressor, a fuel conduit having a metering restriction therein, a metering valve and associated all-speed governor for varying the area of said restriction to select an operating speed for the engine, valve means for varying the fuel metering head across said restriction, means for sensing the pressure rise across the compressor, means for sensing changes in compressor inlet pressure and temperature, means operatively connecting said sensing means to said valve means to effect variation of the fuel metering head at a rate proportional to the square root of compressor pressure rise times a function of compressor inlet pressure modified by compressor inlet temperature, and means for automatically

modifying the action of said valve means as a function of engine speed in the intermediate speed range of the engine during acceleration following resetting of said governor.

10. In a system for controlling the rate of fuel feed to a gas turbine engine having a compressor, a fuel conduit having a metering restriction therein, means for varying the area of said restriction to select an operating speed for the engine, a first valve in flow series with said restriction, a second valve in flow series with said restriction, means for sensing the pressure rise across the compressor, means for sensing changes in compressor inlet pressure and temperature, means operatively connecting said sensing means to said first valve to effect variation of the fuel metering head at a rate proportional to the square root of compressor pressure rise times a function of compressor inlet pressure modified by compressor inlet temperature, and means responsive to changes in engine speed operatively connected to said second valve and arranged to automatically modify the fuel metering head in the intermediate speed range of the engine during acceleration to avoid compressor instability.

11. A system as claimed in claim 10 wherein means are provided for modifying the effect of temperature compensation on the rate of fuel flow in the intermediate speed range of the engine.

12. In a system for feeding fuel to a gas turbine engine having a compressor and a burner or generator to which air and liquid fuel is supplied under pressure, a fuel supply conduit having a metering restriction therein, governor means for controlling the area of said restriction, means for resetting said governor to accelerate and decelerate the engine, valve means for regulating the fuel metering head across said restriction, means for sensing changes in compressor inlet pressure and temperature, means operatively connecting said sensing means to said valve means, second valve means responsive to engine rotational speed in flow controlling relation with said valve means, and means operatively connected to said second valve means for modifying the effects of temperature compensation on the rate of fuel feed during a portion of the acceleration range to avoid compressor instability.

13. In a system for controlling the rate of fuel feed to a gas turbine engine having a compressor, a conduit for conducting fuel to the engine, means for controlling the flow of fuel through said conduit at a rate which is proportional to

$$\frac{\sqrt{P_2-P_1}}{T_1}$$

times a function of P_1 with an exponent between 1 and ½, where P_1 denotes a pressure of the air flowing to the compressor, P_2 denotes a pressure which is generated by the compressor, and T_1 denotes a temperature of the air flowing to the compressor, and means for modifying the said flow of fuel during an acceleration of the engine as a function of an engine operating condition related to power output.

14. In a system for controlling the rate of fuel feed to a gas turbine engine having a compressor, a fuel conduit having a metering restriction therein, valve means responsive to an engine operating condition related to power output for reducing the flow area of said restriction to avoid compressor stall during an acceleration of the engine, and means responsive to a pressure derived from the compressor and in flow controlling relation to said valve means for varying the fuel flow through said restriction with variations in said pressure.

15. A system as claimed in claim 14 plus means for modifying the derived pressure as a function of the temperature of the air flowing to the compressor.

16. A system as claimed in claim 14 wherein said valve means responds to engine speed and said pressure is derived from the discharge side of the compressor.

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CERTIFICATE OF CORRECTION

Patent No. 2,846,846 August 12, 1958

Frank C. Mock

It is hereby certified that error appears in the printed specification of the above numbered patent requiring correction and that the said Letters Patent should read as corrected below.

Column 4, line 5, for "one of both" read -- one on both --; line 44, strike out "be".

Signed and sealed this 17th day of March 1959.

(SEAL)
Attest:

KARL H. AXLINE
Attesting Officer

ROBERT C. WATSON
Commissioner of Patents