Feb. 14, 1956 C. F. WOOD 2,734,340

JET ENGINE POWER REGULATOR

Filed Oct. 13, 1949 6 Sheets-Sheet 1

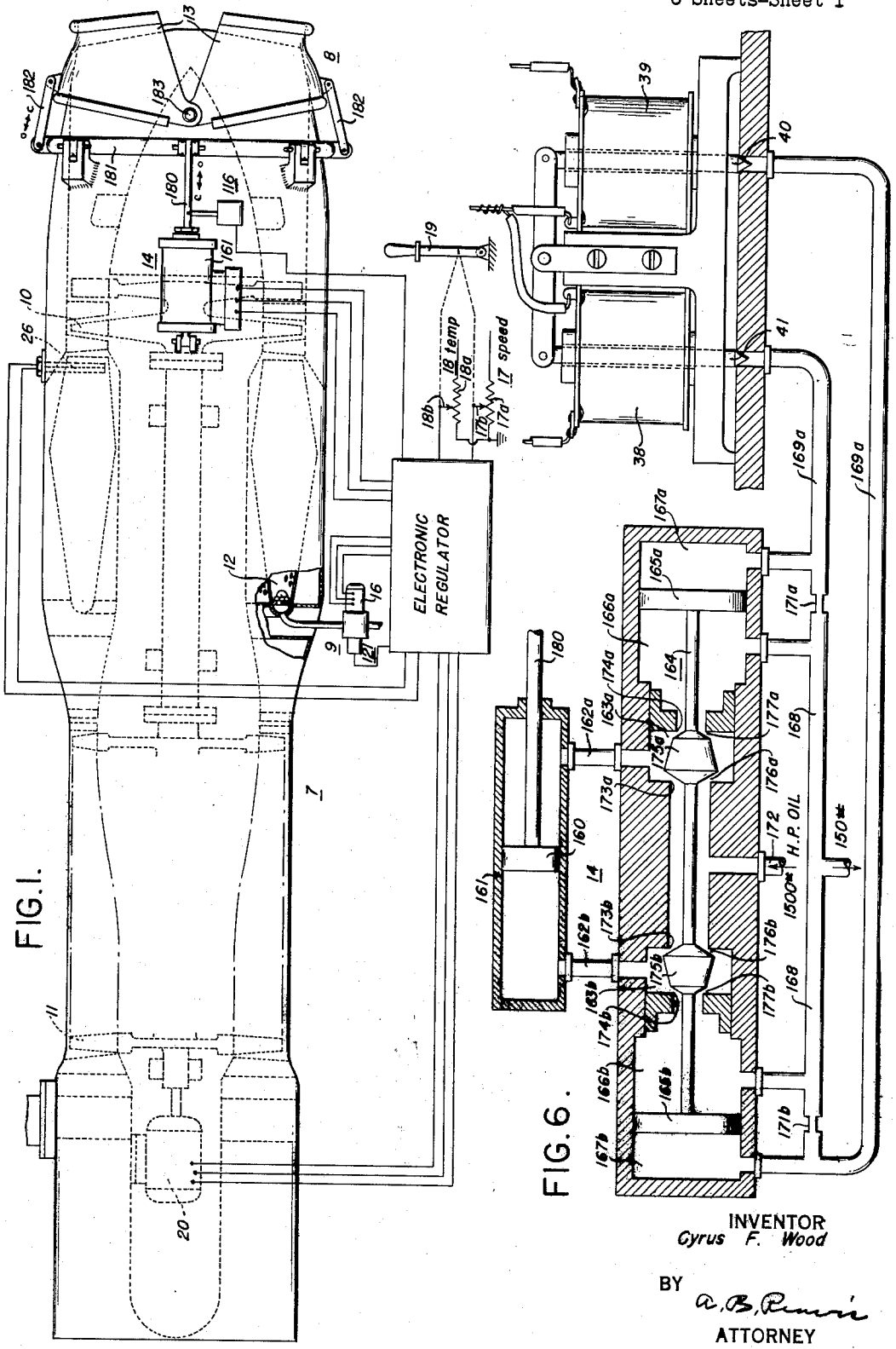


FIG. 1.

FIG. 6.

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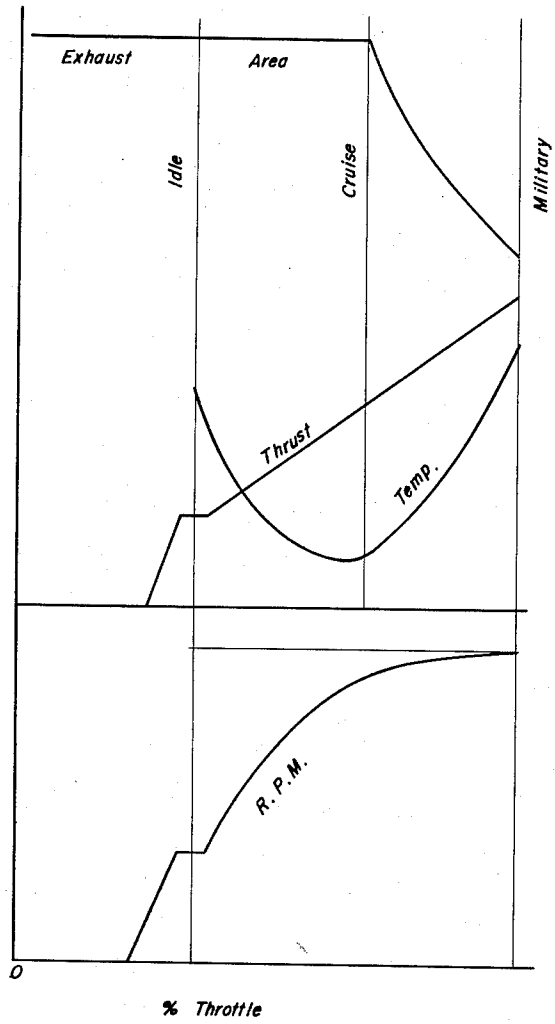
BY
ATTORNEY

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JET ENGINE POWER REGULATOR

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FIG. 2.



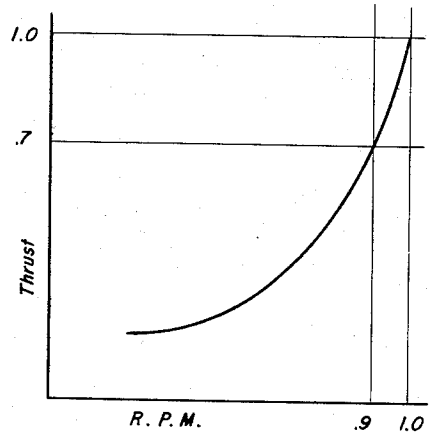


FIG. 3.

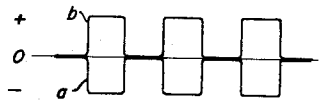


FIG. 7.

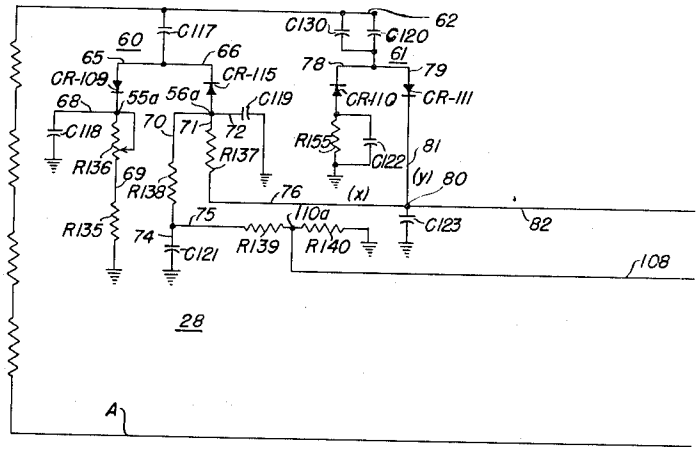
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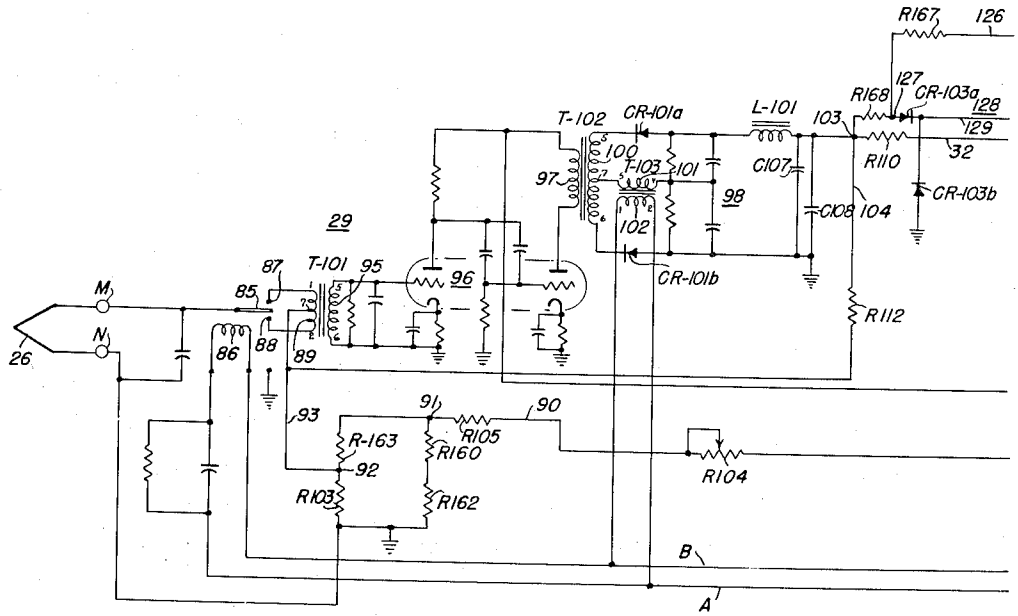
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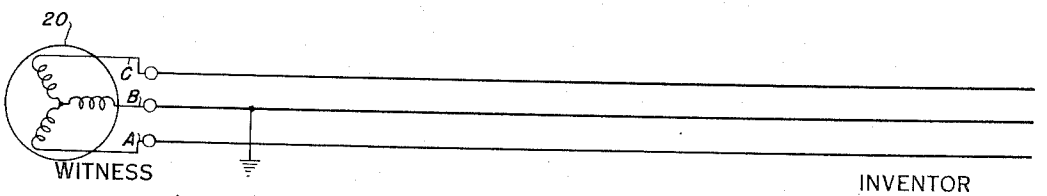
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JET ENGINE POWER REGULATOR

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WITNESS

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FIG. 4a.

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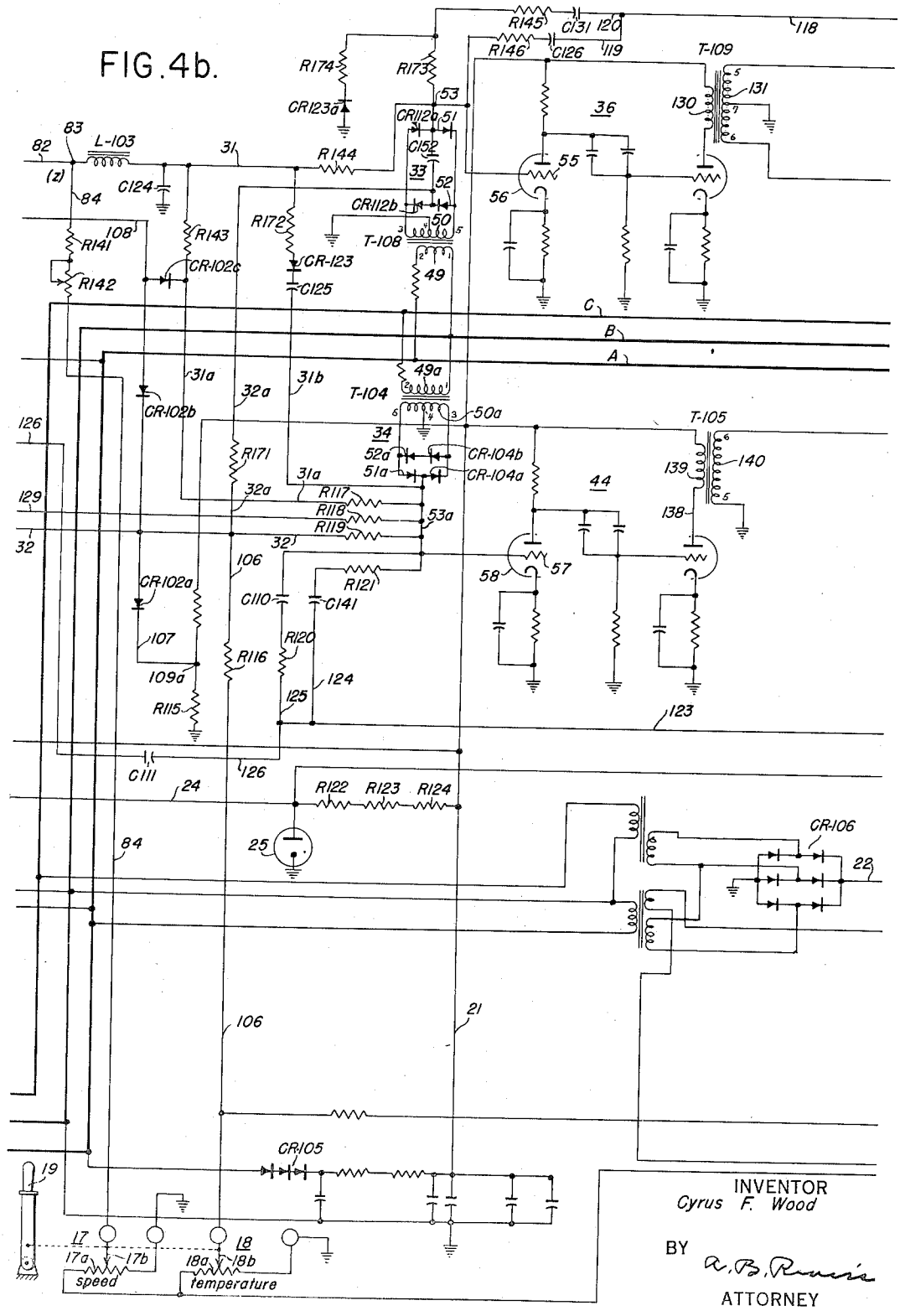
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JET ENGINE POWER REGULATOR

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FIG. 4b.



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JET ENGINE POWER REGULATOR

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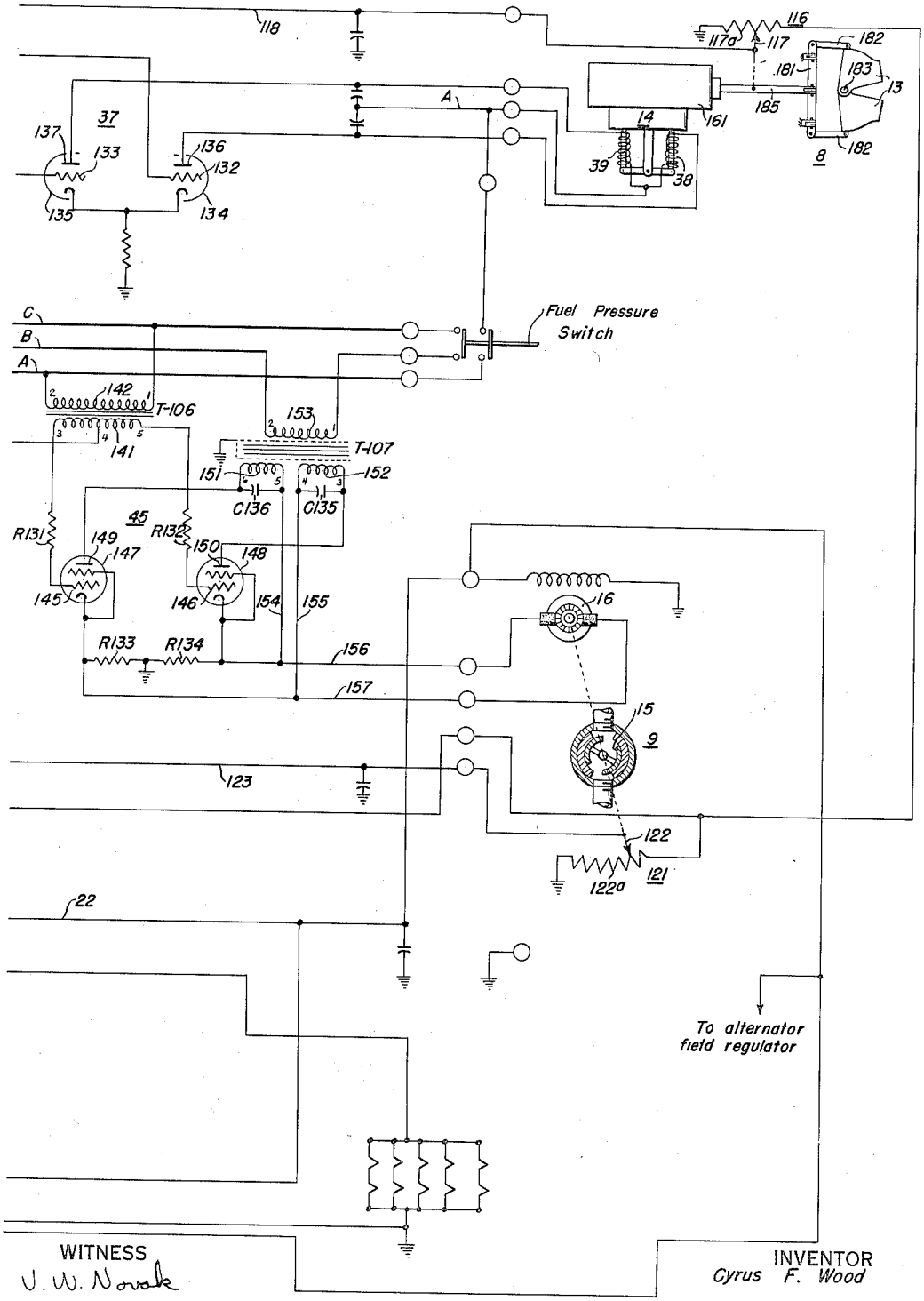


FIG. 4c.

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Feb. 14, 1956 C. F. WOOD 2,734,340

JET ENGINE POWER REGULATOR

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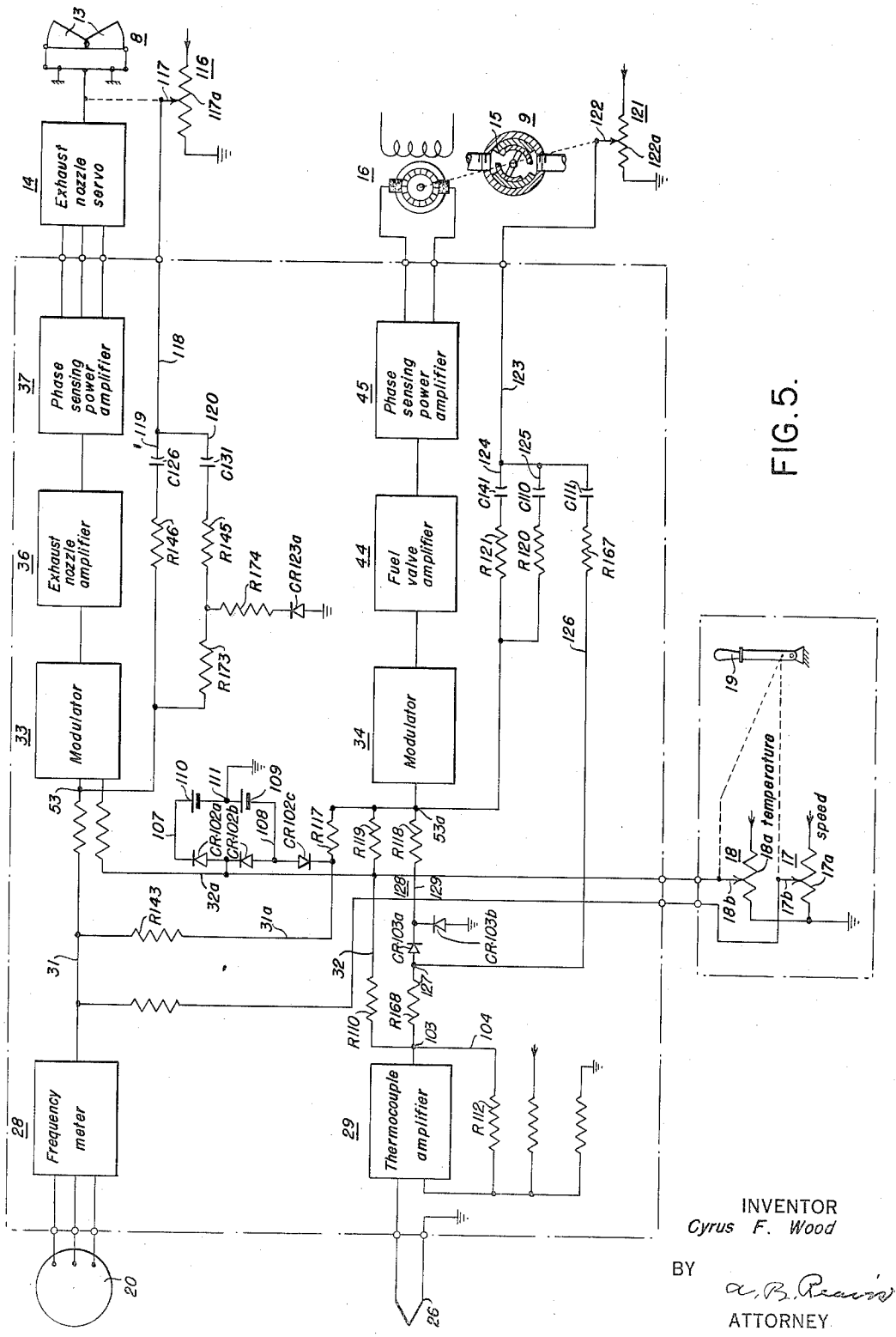


FIG. 5.

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United States Patent Office 2,734,340 Patented Feb. 14, 1956

2,734,340

JET ENGINE POWER REGULATOR

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Application October 13, 1949, Serial No. 121,171

21 Claims. (Cl. 60—35.6)

The invention relates to a jet engine having a fuel value and it has for an object to provide means operative automatically in response to speed and temperature to control the valve with manually-operable means for adjusting the automatic means to vary the thrust.

A further object of the invention is to provide apparatus of the above character wherein, when required, control in response to temperature overrides other control or controls to avoid overheating of the engine.

Another object of the invention is to provide means operating automatically in response to speed and temperature to control both the exhaust nozzle discharge area of a jet engine and the fuel valve thereof together with manually-operable means for adjusting the automatic means to vary the jet thrust.

A more particular object of the invention is to vary the propulsion jet nozzle and the fuel input automatically by means acting in response to speed and temperature such that, in response to speed, the jet nozzle and the fuel valve are moved to increase the nozzle area and the fuel input or to reduce such area and the fuel input, and, in response to temperature, the nozzle and fuel valve are moved to reduce the nozzle area and increase the fuel input or to increase the nozzle area and reduce the fuel input, depending upon the direction of temperature change, together with a member movable manually to adjust said automatic means to vary the thrust.

A further object of the invention is to provide a jet engine power regulator wherein manually-operable means acts through electrical means varied automatically in response to speed to control the exhaust nozzle and the fuel input for variation in jet thrust.

A jet engine involves three variables, namely, engine speed, nozzle area and engine temperature, any two of which may be varied, with the third fixed in relation thereto, to vary the thrust. While in its broader aspects, the present invention contemplates movement of the throttle lever to increase the thrust by increase in fuel input for operation to the extent of the maximum temperature the engine will stand, preferably movement of the throttle lever for increase in thrust involves speed and temperature controlling effects or signals for controlling the fuel input and the exhaust nozzle discharge area for development of propulsion thrust over the thrust range. From idling to about 75 or 80% of full engine speed, the speed signal is used to control increase in fuel input for increase in engine speed and thrust; and, while the signal also tends to operate the exhaust nozzle to increase the nozzle discharge area, as such nozzle is already in maximum area-defining position over this engine speed range, it has no effect thereon, with the result that increase in power, represented by increase in fuel input, is effective for rapid engine acceleration. With the engine operating at 75 or 80% of full speed and the exhaust nozzle in maximum area position, the thrust may be increased over a relatively much larger percentage of the thrust range by a small percentage of engine speed change coupled with restriction in nozzle area. While each of the speed and temperature

signals exerts effects on the exhaust nozzle and on the fuel input, they do so differently—the speed signal tending to increase the fuel input and the exhaust nozzle discharge area from idling to full engine speed and the temperature signal tending to increase the fuel input and to reduce the exhaust discharge area to increase the thrust.

Preferably, control of the engine is effected electrically, the engine driving an alternator operating through a frequency meter and amplifiers to control the exhaust nozzle and the fuel valve and a voltage responsive to temperature is amplified and serves also to control the nozzle and the fuel valve. Such network includes setting adjustable manually to change the fuel input or the latter and the nozzle area to vary the thrust.

More particularly, the invention involves a power regulator controlling the exhaust nozzle and the fuel valve. The regulator includes an alternating current generator driven by the engine, direct current sources, and speed and temperature settings, arranged in the cockpit and operable by means of a throttle lever. Speed and temperature direct current voltages are derived from the alternator output and cooperate with setting direct current voltages from the speed and temperature settings to provide, in the event of deviation of the derived and setting voltages from balanced relation, direct current speed and temperature signals, the polarity of each of which depends upon the direction of deviation. Preferably, as more particularly disclosed and claimed in the application of J. R. Boykin, Serial No. 194,153, filed Nov. 4, 1950, there are provided two modulators, one being the exhaust nozzle modulator and having its output supplied to an electronic amplifying network to control a servo for operating the exhaust nozzle and the other being the fuel input modulator and having its output supplied to an electronic network controlling a servo-motor for operation of the fuel valve to vary the fuel input. Each of the modulators is supplied with direct current inputs including said speed and temperature signals and with alternating current input supplied from the alternator, and operates to provide an alternating current output the amplitude of whose wave is proportional to the direct current input and which output, at alternator frequncy, is impressed on the electronic network. As long as the resultant signal input is zero for each modulator, the alternating current output of the latter to its electronic network is zero; however, if the signal has a negative or positive polarity, the modulator has an alternating current output at alternator frequency with the output wave for a negative signal input 180 degrees out of phase relative to the output when the signal is positive. If the speed signal is negative, the alternating current outputs of the modulators tend to open the exhaust nozzle and to open wider the fuel valve; and, if the speed signal is positive, the contrary operation takes place, the tendency being for the exhaust nozzle to close and for the fuel valve to move in a closing direction. If the temperature signal goes negative, the fuel valve modulator responds in the same way as for a negative speed signal, that is, it causes the fuel input to increase; however, because of the different way in which the temperature signal is applied to the exhaust nozzle modulator, the alternating current output of the latter will be 180 degrees out of phase compared to its output for a negative speed signal, in consequence of which the exhaust nozzle discharge area will be restricted. If the temperature signal goes positive, the contrary operation takes place.

In addition to the signal inputs to the exhaust nozzle and fuel valve modulators, additional inputs are supplied thereto. A stabilizing feedback input is supplied to the exhaust nozzle modulator and the feedback connection is arranged so that a smaller speed or temperature signal is required for moving the exhaust nozzle in a closing direction than in an opening direction. Aside from speed and

temperature inputs supplied to the fuel valve modulator, the latter has a stabilizing feedback input and a temperature-limiting input controlled by movement of the fuel valve, the purpose of the temperature limit being to anticipate temperature, that is, to prevent overtravel of the fuel valve in an opening direction and consequent oversupply of fuel and overheating of the engine.

A more particular object of the invention is to provide a jet engine with an exhaust nozzle and fuel valve, manually-adjustable speed and temperature settings, means responsive to engine speed and temperature and normally balancing the settings, and operative in response to setting adjustment to adjust the exhaust nozzle and the fuel valve for engine operation to restore balance.

A further object of the invention is to provide, with a jet engine having an adjustable exhaust nozzle and a fuel valve, an electrical system responsive to manual settings and to speed and temperature for controlling the exhaust nozzle discharge area and the fuel input so that, by operation of the settings, the fuel valve and nozzle may be automatically controlled for engine operation to develop thrust over the full thrust range.

Another object of the invention is to provide electro-responsive control means for effecting selective automatic control of power of a gas turbine power plant in correlation with operating temperature.

Still another object is the provision of control means of the above character responsive to speed and temperature to control only the fuel input where the exhaust nozzle has a fixed area, or, where the nozzle is of the variable area type, to control both the nozzle area and the fuel input.

The foregoing and other objects are effected by the invention as will be apparent from the following description and claims taken in connection with the accompanying drawing, forming a part of this application, in which:

Fig. 1 is a diagrammatic view of a jet engine having the power regulator applied thereto;

Fig. 2 is a daigrammatic view showing exhaust nozzle discharge area, thrust, temperature, and speed variations in relation to throttle position;

Fig. 3 is a diagram showing the relation of thrust to engine speed at the upper end of the speed range;

Figs. 4*a*, 4*b* and 4*c*, when placed side-by-side in the order given, constitute the wiring diagram of the regulator;

Fig. 5 shows a simplification of the wiring diagram in relation to associated and operated parts;

Fig. 6 is a detail view showing the teeter valve exhaust nozzle servo; and

Fig. 7 is a diagram illustrating waves secured by modulator chopping of direct current negative and positive signals.

In the drawing, there is shown a jet engine, at **7**, having an adjustable exhaust or propulsion jet nozzle, at **8**, and fuel valve, at **9**. In addition to the fuel valve and the jet nozzle, the engine comprises a turbine **10**, a compressor **11**, and a combustor **12**, the compressor delivering air to the combustor for generation of motive fluid to drive the turbine, the turbine driving the compressor and the exhaust from the turbine undergoing further expansion in the nozzle to provide the propulsion jet. The exhaust nozzle has a component or components **13** moved by the servo-motor **14** to vary the exhaust nozzle discharge area and the fuel valve has a member **15** (Figs. 4*c* and 5) moved by the servo-motor **16** to vary the fuel input.

Jet thrust is varied by manual adjustment of a setting of a power regulator controlling the fuel input, or the latter and the exhaust nozzle area, in response to engine speed and temperature. As shown, the regulator has speed and temperature settings, at **17** and at **18**, operated by a throttle lever **19**. Upon movement of the lever for setting adjustment, the balanced relation of the regulator is disturbed and the latter is thereby rendered effective to adjust the fuel valve, or the latter and the exhaust nozzle, for engine operation to restore the balanced relation and

thereby to vary the jet thrust in accordance with lever movement.

The power regulator includes, in addition to the speed and temperature settings, at **17** and at **18**, a three-phase alternator **20** (Fig. 1) driven by the engine; rectifiers **CR–105** and **CR–106** (Fig. 4*b*) supplied from the alternator and furnishing direct current to the lines **21** and **22**, the line **21** supplying current through the resistances **R–122**, **R–123** and **R–124** to the line **24** provided with the voltage regulating tube **25**; and a thermocouple **26** providing a direct current output applied to the terminals M and N (Fig. 4*a*). The line **22** provides direct current voltage for field excitation of the fuel valve motor (Fig. 4*c*), for the alternator field regulator and for the resistances **17***a* and **18***a* of the settings, at **17** and at **18**, and connected in parallel to ground, the settings also including sliders **17***b* and **18***b* moved by the lever **19** along the resistances to reduce the slider voltages for increase in speed and temperature. The line **21** provides plate voltage for various tubes; and the line **24** provides a fixed voltage supply for exhaust nozzle and fuel valve feedback potentiometers and to give a reference for the temperature-responsive means.

The regulator includes speed and temperature networks, at **28** and **29** (Figs. 4*a* and 5), which, in conjunction with the speed and temperature settings, at **17** and at **18**, provide direct current signals supplied by the lines **31** and **32** to the exhaust nozzle modulator, at **33**, and to the fuel valve modulator, at **34**, and each of the modulators has an alternating current output, whose frequency is the same as that of the alternator, and whose amplitude and phase upon the magnitude and polarity of the direct current.

The output of the modulator **33** is amplified in an alternating current exhaust nozzle amplifier **36** and then used to energize the phase-sensitive amplifier, at **37**, whose output is employed to energize either of the magnet windings **38** and **39** for actuation of the teeter valves **40** and **41** (Fig. 6) to cause the hereinafter-described hydraulic exhaust nozzle servo-motor **14** to move the exhaust nozzle component or components **13** to vary the exhaust nozzle discharge area.

The output of the fuel valve modulator **34** at alternator frequency is supplied to the fuel valve amplifier, at **44**, whose output is furnished to the phase-sensitive power stage **45**, furnishing direct current to the reversible motor **16** to move the fuel valve member **15** in either direction.

The speed signal line **31** supplying the modulator **33** has a branch **31***a* for supplying such signal to the fuel valve modulator **34** so that, with a signal tending to open the exhaust nozzle, such signal opens wider the fuel valve to increase the fuel input. While the temperature signal line **32** is connected to both modulators, the connection thereof by the branch **32***a* to the modulator **33** is made in such a manner that a change in the temperature signal to open wider the fuel valve is accompanied by restriction of the exhaust nozzle.

The exhaust nozzle modulator, at **33**, includes a transformer **T-108** having the ends "2" and "1" of its primary **49** connected to phases "A" and "B" and having the ends "3" and "5" of its secondary **50** connected by branches **51** and **52**, the branch **51** including a pair of rectifiers **CR–112***a* conductive from "3" to "5" and the branch **52** including a pair of rectifiers **CR–112***b* conductive from "5" to "3". The secondary has its midpoint "4" tapped to ground. Between the rectifiers **CR–112***a*, the branch **51** is connected to modulator terminal **53**, which is connected to the speed signal line **31** and to the input control grid **55** of the initial vacuum tube **56** of the alternating current amplifier, at **36**.

Each modulator operates as a low resistance path between its terminal and ground on alternate half cycles of its transformer. Referring to the exhaust nozzle modulator **33**, if the speed signal is negative and the left end

"3" of the transformer secondary is positive, then the rectifier branch **51** is conductive and current flows from ground to the terminal **53** to chop the signal to form substantially a square wave *"a"* (Fig. 7) impressed on the amplifier control grid **55**. On the other hand, if the signal is positive, flow occurs from the terminal to ground to produce the square wave *"b"* (Fig. 7) in 180-degree phase relation with respect to square wave *"a"*. On half cycles when "3" is negative, the rectifier branch **52** is conductive and flow between the terminal **53** and ground is blocked. In each case, the modulator output square wave amplitude depends on the signal current magnitude; however, in the two cases, the waves differ in phase dependent upon signal polarity, the wave for a negative signal being 180 degrees out of phase with respect to that for a positive signal. As, after amplification, the modulator output wave is supplied to a phase-sensitive amplifier, the servo-motor is controlled for operation in one direction or the other dependent upon signal polarity.

The temperature signal line branch **32***a* is connected to the branch **52** of the exhaust nozzle modulator between the rectifiers CR–**112***b*, whereby the alternating current output for a temperature signal will be out of phase 180 degrees relative to such output for a speed signal of like polarity, in consequence of which the phase-sensitive amplifier is responsive to a negative speed signal to operate the servo **14** to open the exhaust nozzle and is responsive to a negative temperature signal to operate such servo to restrict the exhaust nozzle. A condenser C–**152** preferably connects the branches **51** and **52** between the rectifiers thereof. In addition to the modulator terminal **53** being connected to the speed signal line **31** and to the grid **55**, such terminal is also connected to the exhaust nozzle feedback, as will be hereinafter described.

The fuel input control modulator, at **34**, is similar to the exhaust nozzle area control modulator, at **33**. It includes a transformer T–**104** having ends "2" and "1" of its primary **49***a* connected to phases "C" and "B" and having the ends "5" and "3" of its secondary **50***a* connected by branches **51***a* and **52***a*, which, respectively, include a pair of rectifiers CR–**104***a* and CR–**104***b*, the rectifiers CR–**104***a* being conductive from "5" to "3" and the rectifiers CR–**104***b* being conductive from "3" to "5". The midpoint of secondary **50***a* is tapped, at "4", to ground. Between the rectifiers CR–**104***a*, the modulator has a terminal **53***a* connected to the grid **57** of the initial vacuum tube **58** of the alternating current amplifier, at **44**. In addition to connection of speed signal branch **31***a* and of the temperature signal line **32** to the terminal **53***a*, the latter also has temperature limit and fuel input feedback connections, as will be described.

The speed-sensitive network, at **28**, is preferably of the type more particularly disclosed and claimed in the application of J. R. Boykin, Serial No. 194,153, filed November 4, 1950, the network comprising (Fig. 4*a*) a reference component, at **60**, a frequency-responsive component, at **61**, and the manual setting at **17**. In operation, the current provided by the reference component, by the frequency-responsive component, and by the manually-operable setting are in balanced relation, with the result that, if the setting voltage is changed, current is supplied to or drawn from the modulator through the speed signal line **31**. As shown, for increase in speed, adjustment of the speed setting, at **17**, lowers the setting voltage so that current is drawn from the signal line, thereby giving a negative signal, which brings about increase in exhaust nozzle area and fuel input to increase the speed until balance is restored. Since the setting direct current voltage is obtained from the alternator through rectifiers, regulation is improved with decrease in setting voltage to increase the speed, closest regulation being secured at top speed when the setting voltage is zero. Thus, as the apparatus balances or zeros at maximum speed, it is definite and stable in its operation.

The reference component **60** comprises an impedance and rectifier network of the doubler type and it includes a condenser C–**117** connected to phase "A." The frequency-responsive component, at **61**, includes parallel condensers C–**120** and C–**130** connected to phase "A." The capacity of the condenser C–**117** is relatively large compared to that of the parallel-connected condensers C–**120** and C–**130** of the frequency counter **61**, with the result that the voltage of the former changes quite rapidly with change in frequency, in consequence of which, for the operating range, a substantially constant reference current and voltage may be provided over a range of frequency variation. On the other hand, because of the relatively much lower capacity of the condensers C–**120** and C–**130** of the frequency-responsive network, the frequency-responsive voltage and current vary substantially in linear relation to speed, with the result that a change in setting voltage produces a signal which brings about change in engine operation until the signal is restored to zero and the reference, the frequency-responsive and the setting current are balanced or the resultant equal to zero.

In addition to the condenser C–**117**, the reference component, at **60**, includes branches **65** and **66** connected to the condenser. The branch **65** includes a rectifier CR–**108**, conductive from the condenser C–**117** through the parallel branches **68** and **69** to ground, the branch **68** including a condenser C–**118** and the branch **69** including resistances R–**135** and R–**136**, the speed-setting resistance R–**136** being adjustable to vary the potential applied to the condenser C–**118** and, therefore, the voltage drop across the condenser C–**117** and the charge of the latter. The resistance R–**136** is preferably adjusted for full speed values of the reference current and voltage provided by the component, at **60**.

The branch **66** is connected through the rectifier CR–**115**, conductive toward the condenser C–**117** from parallel branches **70**, **71** and **72**. The branch **70** is connected, through resistance R–**138** and parallel connections **74** and **75** to ground, the connection **74** including the condenser C–**121** and the connection **75** including the resistances R–**139** and R–**140**. The branch **71** includes a resistance R–**137** connected to the reference line **76**. The branch **72** is connected through the condenser C–**119** to ground.

When phase "A" is positive relative to phase "B," conduction from "A" to "B" occurs through the condenser C–**117**, the rectifier CR–**109**, and the condenser C–**118**. If "B" is positive, then conduction occurs through the condenser C–**119**, rectifier CR–**115** and the condenser C–**117**. Since the condensers C–**118** and C–**119** are in effect connected in series between **55***a* and **56***a*, with the ground, or phase "B," serving as a midpoint connection between the condensers, and since such condensers are charged on successive half cycles, the voltage from **55***a* to **56***a* is double the input voltage to C–**117**.

The cycle counter or frequency-sensitive component, at **61**, includes parallel-connected condensers C–**120** and C–**130**, joining the phase "A" line **62** with the branches **78** and **79**. The branch **78** includes a rectifier CR–**110** conductive from ground, or phase "B," through the parallel-connected resistance R–**155** and condenser C–**122**. The branch **79** includes a rectifier CR–**111** conductive to terminal **80** to which the reference line **76** is connected. On positive half cycles, conduction occurs through the condensers C–**120** and C–**130** and the rectifier CR–**111** to the terminal **80**. On negative half cycles, conduction occurs from ground, or phase "B," through the parallel-connected resistor R–**155** and condenser C–**122**, the rectifier CR–**110**, and the parallel-connected condensers C–**120** and C–**130** to line **62**. Due to the parallel-connected condensers C–**120** and C–**130**, there is provided impedance varying inversely to frequency, in consequence of which direct current in the connection **81** is proportional to frequency.

The terminal **80** is connected to ground through the con-

denser C–123 and through the connection 82 to terminal 83 connected to the speed setting line 84 from the speed setting 17 and including resistances R–141 and R–142, the resistance R–142 being an engine idling speed adjustment and the terminal 82 being also connected through the filter, including the choke L–103 and the condenser C–124, to the speed signal line 31 including the resistance R–144.

Representing the reference direct current in the line 76 (Fig. 4*a*) as "*x*," the frequency current of line 81 as "*y*" and the setting current provided by the line 84 (Fig. 4*b*) as "*z*," a steady state or balanced condition exists when the terminals 80 and 83 are at equal potentials, that is, when "*y*" is equal to "*x*" minus "*z*." If "*z*" is decreased with increase in speed setting, current is drawn through the line from the modulators, that is, a negative signal is furnished to the modulators. On the other hand, if "*z*" is increased, a positive signal is applied. In other words, as long as "*x*" minus "*z*" is made larger than "*y*," a negative signal is applied, and, when the difference is smaller than "*y*," a positive signal is applied.

The temperature network, at 29, includes positive and negative thermocouple terminals M and N. Positive terminal M is connected to an arm 85 vibrated by changing magnetism of the winding 86 connected between phases "A" and "B." The vibrating arm 85 engages opposed contact terminals 87 and 88 connected to ends "1" and "2" of the primary 89 of the transformer T–101 to provide a mechanical chopper for thermocouple current.

A temperature reference voltage is supplied by the line 90 through a temperature adjusting resistance R–104, the resistance R–105, to the terminal 91 of a voltage dividing network having a terminal 92 connected by conductor 93 to the midpoint "7" of the transformer primary 89. The network may include series resistances R–160 and R–162 and series resistances R–163 and R–103 connected in parallel between terminal 91 and ground and the thermocouple negative terminal N.

As long as the voltage at 92 is greater than that at M, the input to the temperature amplifier is negative and the output of the latter is negative.

Upon engagement of the arm 85 with the upper contact 87, current flows from the midpoint "7" to the upper end "1" of the primary, through the contact 87 and the arm 85 to the thermocouple terminal M, whereby the upper end "1" of the primary and the upper end "5" of the secondary 95 of the transformer have negative polarity. Likewise, upon engagement of the arm 85 with the contact 88, the lower ends "2" and "6" of the primary and secondary transformer windings have negative polarity.

The transformer T–101 supplies the two-stage vacuum tube amplifier, at 96, whose output plate circuit includes the primary 97 of the input transformer T–102 of the phase-sensitive detector, at 98. The secondary 100 of the transformer T–102 has its midpoint "7" connected through the secondary 101 of transformer T–103 and rectifiers CR–101*a* and CR–101*b* to the upper and lower ends "5" and "6" of the secondary of the transformer T–102, the rectifiers being conductive toward the latter transformer ends. The primary 102 of the transformer T–103 has its ends "1" and "2" connected to phases "B" and "A." If the portion of the secondary winding of transformer T–102 between "5" and "7" is in phase with the secondary 101 of the transformer T–103, the output of the amplifier is negative. On the other hand, should the thermocouple voltage become higher than the reference, then "6"–"7" of the transformer T–102 would be in phase with the secondary of transformer T–103 and the amplifier would give positive output.

The output of the detector, at 98, after passing through the filter including the choke L–101 and the condensers C–107 and C–108 is supplied to the terminal 103 joined to the feedback connection 104 including the resistance R–112 and connected to midpoint "7" of transformer T–101 and the terminal 103 is also connected, through resistance R–110, to steady state temperature line 32.

The terminal 103 is connected through the steady state temperature control line 32 including the resistor R–110 and the resistor R–119 to the terminal 53*a* of the modulator, at 34.

The steady state temperature control line 32 is supplied by the temperature setting line 106 (Fig. 4*b*) through the resistance R–116 from the slider 18*b* of the temperature setting 18 and it has a branch 32*a* including the resistance R–171 and connected to the branch 52 of the exhaust nozzle modulator 33 between the rectifiers thereof. The branch 32*a* provides for closing of the exhaust nozzle with very little over-speeding. Without this connection, excessive over-speeding would be required for a sufficient positive closing speed signal.

Voltage limiters are associated with the steady state temperature control line 32 to limit the voltage applied thereby to the modulators. To this end, the steady state control line is connected, through rectifiers CR–102*a* and CR–102*b* to regions 107 and 108 whose potentials are slightly higher and slightly lower than zero so that the extent to which the steady state line may become positive is limited by the potential of the region 107 to which the rectifier CR–102*a* is conductive from the line and the extent to which the line may become negative is limited by the potential of the region 108 from which the rectifier CR–102*b* is conductive to the line. The higher and lower potential sources may be positive and negative terminals 109 and 110 of a battery having an intermediate point 111 grounded, as shown in Fig. 5, or the terminal 109*a* may be provided by a point on the plate circuit of the tubes of the amplifier, at 44, separated by the resistance R–115 from ground and the terminal 110*a* (Fig. 4*a*) may be constituted by a point on the branch 75 of the reference component between the resistances R–139 and R–140. Increase in voltage of the line 32 is limited by the voltage of region 107, any tendency of increase in line voltage above that of such region resulting in flow of current from the line through the rectifier 102*a* to the region. On the other hand, the extent to which the steady state line may be decreased in voltage, or go negative, is limited by the potential of the region 108, decrease in line voltage below that of such region resulting in flow of current from the latter to the line.

Negative polarity of the speed signal applied to the fuel valve modulator, at 34, is limited by the rectifier CR–102*c* conductive from a suitable negative source to the speed line branch 31*a* including the resistance R–143 and connected through the resistance R–117 to the terminal 53*a* of the fuel valve modulator, at 34. Thus not only is a check placed on temperature and speed signals to make the fuel valve modulator 34 respond to steady state values of such signals, but, by limiting the signals for fuel valve operation, a required change in fuel input may be more gradually made to suit operating requirements and to avoid over-temperatures. In addition to application of the speed signal by the line 31*a* to the modulator 34, to hasten speed response of the latter, a derivative or rate of change of such signal may be applied by the rate line 31*b* including the series connected resistance R–172, rectifier CR–123 and condenser C–125.

Referring to the exhaust nozzle feedback, as the exhaust nozzle opens, the potentiometer, at 116, is operated, the slider 117 being moved along the resistance 117*a* in the direction to increase the voltage applied to the feedback line 118 connected by parallel branches 119 and 120 (Figs. 4*b* and 5) to the terminal 53 of the exhaust nozzle modulator, the branch 119 including the condenser C–126 and the resistance R–146 and the branch 120 including the condenser C–131 and the resistances R–145 and R–173. Thus, as the exhaust nozzle opens, the voltage applied to the feedback line 118 becomes more positive and the changing voltage results in conduction through the condensers to neutralize the negative speed signal applied to the modulator to limit the effect of the latter in opening the exhaust nozzle.

The exhaust nozzle feedback has provision enabling a speed signal of given positive value to restrict the nozzle more rapidly than a signal of like negative value opens it. Accordingly, a rectifier CR–123*a* conducts from ground through the resistance R–174 to the parallel branch 120 between the resistances R–145 and R–173, the purpose of the rectifier being to conduct from ground to limit the neutralizing effect of a given voltage change at the potentiometer slider 117 in a decreasing direction.

Referring to the fuel input feedback, as the fuel is increased, the potentiometer, at 121, is operated, the slider 122 is movable along a resistance 122*a* in a direction to increase the potential applied to the feedback line 123 connected through parallel branches 124 and 125 to the modulator terminal 53*a*, the branch 124 including the condenser C–141 followed by the resistance R–121 and the branch 125 including the condenser C–110 preceded by the resistance R–120, the follow-up signal applied by the branch 124 being stabilized by that applied through the branch 125. The slider voltage applied through the parallel-connected condensers and resistances tends to neutralize the resulting signal applied to the modulator terminal 53*a*.

The feedback line 123 also has a branch 126 including the condenser C–111 and the resistance R–167 and the branch is connected to the section 127 of the temperature limit line, at 128, such section being connected, through the resistance R–168, to the temperature network terminal 103 and through the rectifier CR–103*a* to the section 129 connected, through the resistance R–118, to the modulator terminal 53*a*. If the section 129 of the temperature limit line tends to become negative in relation to ground, then conduction from the latter occurs through the rectifier CR–103*b*, thereto.

As long as a steady state condition obtains, then no feedback voltage is applied through the branch 126 to the temperature limit line section 127; however, positive change of feedback voltage relative to ground has the effect of neutralizing the negative temperature signal supplied to section 127, in consequence of which the modulator input is rapidly neutralized and movement of the fuel valve in an opening direction is limited. Thus, the feedback operates in a manner anticipatory of temperature, it restricting the fuel input to avoid excessive rise in temperature. On the other hand, if the section 129 of the temperature limit line tends to become negative in relation to ground, then conduction from ground thereto occurs through the rectifier CR–103*b*. The main effect of the feedback of the fuel signal is to override the temperature signal at low speeds, therbey aiding in acceleration in that excessive opening of the fuel valve is avoided.

Referring more particularly to the exhaust nozzle alternating current amplifier, at 36, and the phase-sensitive amplifier, at 37, the amplifier, at 36, has its plate circuit including the primary 130 of the transformer T–109, the transformer including a secondary 131 having its upper and lower ends "5" and "6" connected, respectively, to the grids 132 and 133 of the tubes 134 and 135 whose plates 136 and 137 are connected through the magnet windings 38 and 39 to phase "A." The midpoint "7" of the transformer secondary 131 is connected to ground. When the upper end "5" of the transformer secondary 131 is positive at the same time phase "A" is positive, then the tube 134 conducts more than tube 135 and the servo 14 is driven in the direction to open the exhaust nozzle.

It will be apparent that polarity of the secondary of the transformer T–109, in relation to the alternating current wave applied to the plates 136 and 137, depends upon the phase of the exhaust nozzle modulator output wave, if a negative signal is applied to the modulator, then the tube 134 is conductive and the servo 14 is operated to move the exhaust valve in an opening direction. On the other hand, if the signal input is positive, then the lower end of the transformer secondary will be positive when the plate 137 is positive and the tube 135 is then conductive to energize the winding 39 for operation of the servo to move the exhaust valve in a closing direction.

The fuel valve amplifier, at 44, is similar to the exhaust nozzle amplifier, at 36, it having the plate circuit 138 of its final stage including the transformer primary 139 of the input transformer T–105 for the phase-sensing power amplifier, at 45.

The secondary 140 of the transformer T–105 has its upper end "6" connected to the midpoint "4" of the secondary 141 of the transformer T–106, whose primary 142 has its ends "2" and "1" connected to phases "A" and "C." The lower end "5" of the transformer secondary 140 is connected to ground. The ends "3" and "5" of the transformer secondary 141, corresponding to the ends "2" and "1" of the primary 142, are connected, through resistances R–131 and R–132, to grids 145 and 146 of the thyratrons 147 and 148, the latter having their plates 149 and 150 connected to the outer ends "6" and "3" of the secondaries 151 and 152 of the transformer T–107 having a primary 153 whose ends "2" and "1" connected to the phases "B" and "C." The adjacent ends "5" and "4" of the transformer secondaries 151 and 152 are connected, through condensers C–136 and C–135, to the ends "6" and "3" and are connected through the conductors 154 and 155 to the cathodes of the tubes 148 and 147, respectively, and through resistances R–133 and R–134 to ground. The conductors 154 and 155 provide supply leads 156 and 157 for the motor 16.

With the plates 149 and 150 of the thyratrons 147 and 148 rendered alternately positive by the transformer T–107, if, with a plate positive, the corresponding grid voltage becomes sufficiently positive to start conduction, then the tube remains conductive independently of grid voltage until the plate voltage becomes negative. In the arrangement shown, if the fuel valve modulator signal is negative, then the alternating current wave applied by the amplifier, at 44, causes the upper end "6" of the secondary of the transformer T–105 to be positive when the plate 150 is positive, and, just as soon as the potential applied to the grid 146 is sufficient to start conduction, the tube becomes conductive and remains so until its plate becomes negative at the beginning of the next half cycle, at which time the plate 149 of the tube 147 becomes positive, but, as the end "6" of transformer T–105 then has negative polarity, the amplitude of the wave applied to the grid 145 is reduced, in consequence of which the starting voltage occurs later in the cycle and the conduction period of the tube is thereby shortened. If the modulator signal is positive, the contrary operation takes place, the terminal "6" of transformer T–105 then being positive when the plate 149 is positive.

Assuming no signal current is applied to the fuel valve modulator, then, as the plates of the thyratrons 147 and 148 are made alternately positive in 120-degree phase relation with respect to the grids thereof, the tubes will be alternately energized. As 156 is positive relative to 157 to drive the motor in the direction for increased fuel input when the tube 147 is energized and as 157 is positive relative to 156 to drive the motor in the opposite direction to decrease the fuel input, it will be apparent that, so long as there is no signal applied to the fuel valve modulator, the motor 16 will be energized alternately for operation in opposite directions to equal extents with the result that no movement thereof occurs. If a negative signal is applied to the fuel valve modulator, then the terminal "6" of transformer T–105 will be in phase with the plate 150 when the latter is positive and the voltage of the transformer T–105 will add to that of transformer T–106 to increase the amplitude of the wave applied to the grid 146. On the succeed-

ing half cycle, the plate **149** will be positive, but the excitation of the grid **145** will be reduced by the transformer T–105. Therefore, the periods of motor energization for increase in fuel preponderate over those for decrease therein, the magnitude of preponderance depending upon the magnitude of the signal and the direction of rotation of the motor depending upon the signal polarity.

Referring more particularly to the exhaust nozzle hydraulic servo-motor, as shown in Fig. 6, it includes an operating piston **160** in the cylinder **161** having opposite ends connected by passages **162***a* and **162***b* to the chambers **163***a* and **163***b*. A relay, at **164**, has end pistons **165***a* and **165***b* separating inner cylinder spaces **166***a* and **166***b* from outer cylinder spaces **167***a* and **167***b*. The inner cylinder spaces **166***a* and **166***b* are connected by a passage **168** in which a substantially constant pressure (for example, 150 p. s. i.) is maintained and the outer cylinder spaces **167***a* and **167***b* are connected to passages **169***a* and **169***b* connected by orifices **171***a* and **171***b* to the passage **168**.

A substantially constant flow of oil (for example, 2.5 g. p. m.) is supplied from the passage **172** through inner openings **173***a* and **173***b* to the chambers **163***a* and **163***b* and from the latter through the outer openings **174***a* and **174***b* to the inner cylinder spaces **166***a* and **166***b* and thence to the low-pressure passage **168**.

The relay includes plug valves **175***a* and **175***b* in the chambers **163***a* and **163***b* and cooperating with the inner openings **173***a* and **173***b* to provide inner orifices **176***a* and **176***b* and cooperating with the outer openings **174***a* and **174***b* to provide outer orifices **177***a* and **177***b*.

The teeter valves **41** and **40** control discharge from the passages **169***a* and **169***b* for the outer cylinder spaces **167***a* and **167***b*. Assuming differential energization of the magnet windings **38** and **39** to restrict the discharge from one teeter valve and increase that from the other, a differential pressure will thereby be created in the outer cylinder spaces **167***a* and **167***b*, in consequence of which the relay **164** will be moved.

Assuming the relay, at **164**, to move to the left in consequence of higher pressure in the right cylinder space **167***a*, the right inner and the left outer orifices **176***a* and **177***b* will be restricted in flow area while the right outer and the left inner orifices **177***a* and **176***b* will be increased in flow area, with the result that the pressure in the right chamber **163***a* will be reduced while that in the left chamber **163***b* will be increased and the differential pressure thereby created is effective to move the operating piston **160** to the right. On the other hand, if the relay is moved to the right, the contrary operation takes place, the operating piston **160** being moved to the left.

As shown, the piston **160** has a rod **180** mechanically connected to the "eyelids," or movable members **13**, defining the exhaust nozzle area. Rearward motion of the rod increases the nozzle area and vice versa. As shown in Figs. 1 and 4*c*, the rod **180** is pivotally connected to a curved rocker **181** carried by the housing and connected by links **182** to the eyelid members **13** pivotally connected to the housing at **183**.

Because of the larger radii of the inner orifices **176***a* and **176***b* relative to the outer orifices **177***a* and **177***b*, the pressures in the chambers **163***a* and **163***b* apply opposed inward forces to the plugs **175***a* and **175***b* and the liquid under high pressure supplied by the pipe **172** applies opposed outward forces to such plugs, the outward forces being relatively larger than the inward forces. With the pressures in the teeter valve spaces **167***a* and **167***b* the same, the forces thereof applied to the relay pistons **165***a* and **165***b* balance and the right-hand forces applied to the plugs balance the left-hand forces applied to the latter.

Assuming that, due to teeter valve operation, the pressure in right-hand space **167***a* is increased and that in left-hand space **167***b* is decreased, a left-hand force is thereby applied to the relay to move it to the left; however, as the relay moves to the left, the pressure drop across the orifice **176***a* increases while that across the orifice **176***b* decreases, in consequence of which the pressure in the chamber **163***a* decreases and that in the chamber **163***b* increases, giving a resultant right-hand force which increases to balance the left-hand force due to teeter valve operation. Therefore, the extent of relay movement depends upon teeter valve movement and the relay will apply chamber differential pressure to move the operating piston as long as the teeter valves are not in equilibrium.

Upon deenergization of the energized solenoid **38** or **39**, the balanced relation of pressures in the teeter valve spaces **167***a* and **167***b* is restored, the necessary flow therefor occurring through the orifices **171***a* and **171***b*, and the teeter valves assuming an equilibrium position. With the right-hand forces applied to the plugs larger than the left-hand forces applied thereto to give a differential balancing the differential applied to the pistons **165***a* and **165***b*, as the pressures in the spaces **167***a* and **167***b* are restored to equilibrium, the unbalanced differential applied to the plugs is effective to move the relay to a position where the right-hand and left-hand forces applied to the plugs balance.

The floating type servo, at **14**, provides the power required to adjust the exhaust nozzle area in accordance with signal inputs to the modulator, at **33**; and, as the servo is motivated hydraulically under control of the output of the phase-sensitive amplifier, at **37**, the power requirements of the latter are relatively small. On the other hand, as the power required to move the fuel valve **15** is comparatively small, such movement may be effected by an electric motor **16** energized by the electronic output of the amplifier **45**.

The foregoing apparatus operates as follows: The operator moves the throttle lever **19** to adjust the regulator to cause operation of the latter to vary the thrust. The regulator controls the exhaust nozzle area in response to magnitude and polarity of signals applied to the modulator **33** and it controls the fuel valve in response to the magnitude and polarity of the algebraic sum of signals applied to the modulator **34**. Each modulator operates to provide an alternating current wave whose amplitude depends upon the direct current signal input, with the wave for a negative signal out of phase 180 degrees with respect to that for a positive signal. The alternating current output of each modulator is amplified and furnished to a phase-sensitive amplifier supplying the corresponding servo, the arrangement being such that negative speed signals cause increase in nozzle area and in fuel input and vice versa and negative temperature signals cause decrease in nozzle area and increase in fuel input and vice versa.

The direct current signal inputs are provided by means responsive to engine speed and temperature and by manually-controlled adjustments, the speed signal, by means of the manually-movable setting **17**, being made to give a negative speed signal effective on the modulator **33** to cause opening of the exhaust nozzle and effective on the modulator **34** to increase the fuel input.

Temperature-responsive means operates to provide an output, normally negative, and which, with positive and negative limits, provides a steady state signal which is made negative by throttle adjustment for increase in speed and the steady state signal so provided and modified is applied to both modulators. The steady state signal is applied to the exhaust nozzle modulator in such manner that the alternating current wave caused thereby is 180 degrees out of phase with respect to the wave caused by a speed signal of like polarity with the result that a negative temperature signal tends to close the exhaust nozzle and open the fuel valve.

The means by which a speed signal is applied to the fuel valve modulator has means limiting the extent of

negative polarity of such signal tending to increase the fuel input.

In addition to the speed and temperature signal inputs for the modulator **33**, the latter is also supplied with neutralizing or follow-up inputs dependent upon exhaust nozzle position, that is, if a negative signal is applied to the modulator to bring about opening of the exhaust nozzle, such opening results in the application of an increase in positive signal to the modulator to neutralize the negative signal, whereupon movement of the exhaust nozzle ceases. The follow-up or feedback connection includes means whereby a smaller signal is required for closing the exhaust nozzle than for opening it, whereby the nozzle may be closed more rapidly than it is opened.

In addition to the limited speed signal and the steady state temperature signal applied to the fuel valve modulator **34**, there is a temperature limit signal and fuel valve feedback or follow-up signals.

Assuming a negative signal to be applied to the fuel valve modulator, then, as the fuel valve opens, an increase in positive signal is fed back to neutralize the negative signal to stop opening of the fuel valve.

A temperature limit signal is applied to the modulator to avoid excessive fuel input, particularly when accelerating. To this end, there is provided the fuel limit line, at **128**, including first and second sections **127** and **129** connected by a rectifier CR–**103***a* conductive from the first section to the second section, with the first section connected to the outlet terminal of the thermocouple amplifier through a resistance and the second section connected through a resistance to the modulator. Normally, the potential of the first section is negative, the second section is kept from going negative by a rectifier CR–**103***b* conductive from ground thereto, and the resistance R–**118** connecting the second section to the modulator assures, not only of a signal applied to the latter which is normally negative relative to the second section at ground potential, but it serves to limit the extent to which the terminal **53***a* of the modulator **34** may go negative. As long as no direct current is fed back from the fuel valve to the first section, there is no effect on the steady state operation; however, just as soon as the feedback is sufficient to make the first section positive relative to ground, the negative signal causing opening of the fuel valve is neutralized, whereby opening of the fuel valve and consequent rise in engine temperature are limited.

While my invention contemplates obtaining speed and temperature signals in any suitable manner with application of such signals to operate the exhaust nozzle and fuel valve servos, by the use of modulators, each providing an alternating current wave whose amplitude depends upon magnitude of the direct current signal and whose phase depends upon the signal polarity, it is possible to use alternating current amplifiers supplying phase-sensitive amplifiers which deliver power for servo operation in the proper direction, as more particularly disclosed and claimed in the application of Boykin aforesaid. Alternating current amplification is advantageous in that no difficulty is experienced in bringing the grid voltages to zero, whereby the apparatus may readily and definitely be brought to the zero condition without the necessity of bringing grid potentials into balance for that condition with inherent complication of apparatus for that purpose as well as errors or variations introduced because of tube characteristic variations.

Since the setting voltages are obtained from rectifiers supplied from the alternator, such voltages are lowered for increase in speed and temperature, with the result that the closest regulation is secured at top speed and temperature.

Referring to Figs. 2 and 3, with the engine idling, as the throttle lever is moved in the direction of increased speed and thrust, the changing temperature setting has no effect on the automatic control mechanism until the speed reaches about 75 or 80 per cent of full speed, the control during this acceleration period being mainly in response to speed with the exhaust nozzle fully open. At about said fractional speed, the temperature control comes into play mainly for the purpose of closing the exhaust nozzle so that in going from said 75 or 80 per cent speed point to full speed, the ratio of thrust change to speed change rapidly increases with the result that, at full speed, and as may be seen from Figs. 2 and 3 and particularly Fig. 3, only a very small percentage of speed change is required for a large percentage of thrust change. Therefore, while the operator moves the throttle lever to vary the thrust, this result is accomplished by varying the nozzle and the fuel input through the intermediary of the automatic control arrangement responsive to speed and temperature, the arrangement assuring of correlated operation of the exhaust nozzle and fuel valve in response to speed and temperature with the maximum development of thrust without going to temperatures too high for turbine toleration.

While the invention has been shown in but one form, it will be obvious to those skilled in the art that it is not so limited, but is susceptible of various changes and modifications without departing from the spirit thereof.

What is claimed is:

1. In a jet engine provided with a fuel valve having a member movable to vary the fuel input and a propulsion jet nozzle having a component movable to vary the nozzle area, means operated in response to engine speed and temperature for moving the movable component of the jet nozzle and for moving the movable member of the fuel valve, a manually-movable member for adjusting said means for movement of the jet nozzle movable component and the fuel valve member to vary the thrust, and means responsive to movements of the movable valve member and of the jet nozzle movable component to regulate the response of said operated means.

2. In a jet engine provided with a fuel valve having a member movable to vary the fuel input and a propulsion jet nozzle having a component movable to vary the nozzle area, means operated in response to engine speed to move the jet nozzle movable component and the fuel valve member so that both are moved in opening directions for causing increase in engine speed and vice versa; means operated in response to engine temperature to move the fuel valve member and the jet nozzle movable component so that the fuel valve member is moved in an opening direction and the jet nozzle movable component is moved in a closing direction for causing an increase in engine temperature, and vice versa; settings for said speed-responsive and temperature-responsive means; and manual means for moving said settings for movement of the fuel valve member and of the jet nozzle movable component to vary the thrust.

3. In a jet engine provided with a fuel valve having a member movable to vary the fuel input and a propulsion jet nozzle having a component movable to vary the nozzle area, first means including an adjustable setting and operated in response to engine speed to move the jet nozzle movable component and the fuel valve member so that both are moved in opening directions for causing increase in engine speed and vice versa; second means including an adjustable setting and operated in response to engine temperature to move the fuel valve member and the jet nozzle movable component so that the fuel valve member is moved in an opening direction and the jet nozzle movable component is moved in a closing direction for causing an increase in engine temperature, and vice versa; manual means for moving said settings for movement of the fuel valve member and of the jet nozzle movable component to vary the thrust; means responsive to movement of the jet nozzle movable component to regulate response of said movable component to both said first and second operated means; and means responsive to movement of the movable valve member to regulate the response of

said movable valve member to both the first and second operated means.

4. In a jet engine provided with a fuel valve having a member movable to vary the fuel input and a propulsion jet nozzle having a component movable to vary the nozzle area, first means including an adjustable setting and operated in response to engine speed to move the jet nozzle movable component and the fuel valve member so that both are moved in opening directions for causing increase in engine speed and vice versa; second means including an adjustable setting and operated in response to engine temperature to move the fuel valve member and the jet nozzle movable component so that the fuel valve member is moved in an opening direction and the jet nozzle movable component is moved in a closing direction for causing an increase in engine temperature, and vice versa; manual means for moving said setting for movement of the fuel valve member and of the jet nozzle movable component to vary the thrust; apparatus operated in response to movement of the jet nozzle movable component to regulate response of the latter to both said first and second operated means and including means effective to cause less limitation of closing response than of opening response; and means responsive to movement of the movable valve member to regulate response of the movable valve member to said first and second operated means.

5. In a jet engine provided with a fuel valve having a member movable to vary the fuel input and a propulsion jet nozzle having a component to vary the nozzle area, first servo-motor means for moving the valve member, means for controlling said servo-motor means in response to engine speed and temperature, second servo-motor means for moving the jet nozzle movable component, means responsive to engine speed and temperature for controlling the second servo-motor means, means operated by movement of said jet nozzle movable component to regulate the response of the controlling means for the second servo-motor means, and means operated by movement of the movable valve member to regulate the response of the controlling means for the first servo-motor means.

6. In a jet engine provided with a fuel valve having a member movable to vary the fuel input and a propulsion jet nozzle having a component movable to vary the nozzle area, means, including settings, providing electric signals dependent upon engine speed and temperature, means responsive to said signals for moving the movable component of the jet nozzle to vary the area of the latter and for moving said member of the fuel valve to vary the fuel input, means responsive to movement of the nozzle component to develop electric signals for regulating the effect of the signal causing movement thereof and responsive to movement of the said member of the fuel valve to develop electric signals for regulating the effect of the signal causing movement of the valve member, and means manually movable to adjust said settings for said electric signal means for nozzle area and fuel input variation to vary the thrust.

7. In a jet engine provided with a fuel valve having a member movable to vary the fuel input and a propulsion jet nozzle having a component movable to vary the nozzle area, means including settings providing electric signals dependent upon engine speed and temperature, means responsive to said signals for moving the movable component of the jet nozzle to vary the area of the latter and for moving said member of the fuel valve to vary the fuel input, means responsive to movement of the nozzle component to develop electric signals for regulating the signal causing movement thereof, such signals being smaller for movement in the closing direction than in the opening direction, whereby such movable component may be moved in a closing direction more rapidly than it is moved in the opening direction and means responsive to movement of the said member of the fuel valve to develop electric signals for regulating the effect of the signal causing movement of the valve member, and means manually movable to adjust said settings for nozzle area and fuel input variation to vary the thrust.

8. In a jet engine having a propulsion jet nozzle and provided with a fuel valve having a member movable to vary the fuel input, means, including settings, providing electric signals dependent upon engine speed and temperature, means responsive to said signals for moving said member of the fuel valve to vary the fuel input, means responsive to movement of said valve member in the direction to increase the fuel input to develop an electrical temperature anticipating signal for aiding said temperature signal in limiting movement of the valve member in the direction for increased fuel input, and means manually movable to adjust said settings for said electric signal means for fuel input variations to vary the thrust.

9. In a jet engine provided with a fuel valve having a member movable to vary the fuel input and a propulsion jet nozzle having a component movable to vary the nozzle area, means, including settings, providing electric signals dependent upon engine speed and temperature, means responsive to said signals for moving the movable component of the jet nozzle to vary the area of the latter and for moving said member of the fuel valve to vary the fuel input, means responsive to movement of said valve member in the direction to increase the fuel input to develop an electrical temperature anticipating signal for aiding said temperature signal in limiting movement of the valve member in the direction for increased fuel input, and means manually movable to adjust said settings for said electric signal means for nozzle area and fuel input variation to vary the thrust.

10. In a jet engine provided with a fuel valve having a member movable to vary the fuel input and a propulsion jet nozzle having a component movable to vary the nozzle area, means, including settings, providing electric signals dependent upon engine speed and temperature, means responsive to said signals for moving the movable component of the jet nozzle to vary the area of the latter and for moving said member of the valve to vary the fuel input, means responsive to movement of the nozzle component to develop electric signals for regulating the signal causing movement thereof, such signals being smaller for movement in the closing direction than in the opening direction, whereby the component may be moved more rapidly in the closing direction than in the opening direction and means responsive to movement of the valve member to develop electric signals for regulating the signal causing movement thereof, means responsive to movement of said valve member in the direction to increase the fuel input to develop an electric temperature anticipating signal for aiding said temperature signal in limiting movement of the valve member in a fuel input increasing direction, and means manually movable to adjust said settings for said electric signal means for nozzle area and fuel input variation to vary the thrust.

11. In a jet engine provided with a propulsion jet nozzle and a fuel valve, the combination of, means responsive to engine speed, means responsive to engine temperature, manually-operable speed and temperature settings, means responsive to the speed-responsive means and to the speed setting to provide a speed signal, means responsive to the temperature-responsive means and to the temperature setting to provide a temperature signal, means responsive to the speed signal pursuant to adjustment of the speed setting for increase in speed to increase the jet nozzle discharge area and the fuel input, means responsive to the temperature signal pursuant to adjustment of the temperature setting for increase in temperature to decrease the jet nozzle discharge area and to increase the fuel input, a feedback responsive to jet nozzle movement for regulating the movement of the nozzle in response to the speed and temperature signals, and a feedback responsive to fuel valve movement for regulating the movement of the valve in response to the speed and temperature signals.

12. In propulsion apparatus, the combination of, a

prime mover, means for supplying fuel for operation of the prime mover, a normally-balanced electrical network, means providing electrical outputs dependent on prime mover speed and temperature and for supplying said outputs to said network, electrical means operative in response to unbalancing of said network pursuant to changes in speed and temperature to vary the input of fuel by said supply means, means responsive to operation of the last-named electrical means to regulate the rebalancing of the network, and settings adjustable to vary the speed and temperature values for network balance.

13. In aircraft propulsion apparatus, the combination of, a gas turbine, a device energized by operation of the turbine to provide propulsion thrust and adjustable to vary the thrust, means for supplying fuel for operation of the turbine, a normally-balanced electrical network, means providing electrical outputs dependent on turbine speed and temperature and for supplying the outputs to said network, electrical means operative in response to unbalancing of said network pursuant to turbine speed and temperature changes to vary the input of fuel by said supply means and to adjust the propulsion device, means responsive to operation of the last-named means to regulate the rebalancing of the network, and manually-operable speed and temperature settings for the network and adjustable to vary the speed and temperature values for network balance to vary the propulsion thrust.

14. In a jet engine having a propulsion jet nozzle and provided with a fuel valve having a member movable to vary the fuel input, an alternator driven by the engine, a frequency meter supplied by the alternator and operative to provide a speed signal, a thermocouple providing an electrical output responsive to engine temperature, an amplifier operated in response to thermocouple output to provide a temperature signal, a motor for moving the valve member, an amplifier responsive to said speed and temperature signals for controlling the motor, and adjustable setting means for varying the signals to vary the input of fuel for variation in thrust.

15. In a jet engine having a propulsion jet nozzle and provided with a fuel valve having a member to vary the fuel input, an alternator driven by the engine, a frequency meter supplied by the alternator and operative to provide a speed signal, a thermocouple providing an electrical output responsive to engine temperature, an amplifier operated in response to thermocouple output to provide a temperature signal, a motor for moving the valve member, an amplifier responsive to said speed and temperature signals for controlling the motor, adjustable setting means for varying the signals to move the valve member to vary the input of fuel for variation in thrust, and feedback means operated by valve member movement to modify the signal change applied to the last-named amplifier for producing such movement.

16. In a jet engine having a propulsion jet nozzle and provided with a fuel valve having a member to vary the fuel input, an alternator driven by the engine, a frequency meter supplied by the alternator and operative to provide a speed signal, a thermocouple providing an electrical output responsive to engine temperature, an amplifier operated in response to thermocouple output to provide a temperature signal, a motor for moving the valve member, an amplifier responsive to said speed and temperature signals for controlling the motor, adjustable setting means for varying the signals to move the valve member to vary the input of fuel for variation in thrust, feedback means operated by valve member movement to modify the signal change applied to the last-named amplifier for producing such movement, and means for limiting the speed signal applied to the last-named amplifier.

17. In a jet engine provided with a fuel valve and a variable area jet nozzle having a movable nozzle element, the combination of means responsive to engine speed, means responsive to engine temperature, manually operable speed and temperature settings, means responsive to the speed responsive means and to the speed setting to provide a speed error signal such that the speed error is positive whenever the engine speed is greater than the speed setting, means responsive to the temperature responsive means and to the temperature setting to provide a temperature error signal such that the temperature error is positive whenever the temperature is greater than the temperature setting, means responsive to the speed error signal to increase the jet nozzle discharge area and the fuel input when the speed error signal is negative, means responsive to the temperature error signal to decrease the jet nozzle discharge area and to increase the fuel input when the temperature error signal is negative, a feedback responsive to jet nozzle movement for regulating the movement of the nozzle element in response to the speed and temperature error signals, and a feedback responsive to fuel valve movement for regulating the movement of the valve in response to speed and temperature error signals.

18. In an apparatus as set forth in claim 17, the combination of a fixed maximum temperature setting, means responsive to the temperature responsive means and to the fixed maximum temperature setting to provide a temperature limiting signal, and limiter means for restricting the amount of increase in fuel input with relation to the speed error signal, such that the temperature limiting signal may assume control of the fuel input to the engine to prevent development of excessive temperatures.

19. In an apparatus as set forth in claim 17, the combination of a fixed maximum temperature setting, means responsive to the temperature responsive means and to the fixed maximum temperature setting to provide a temperature limiting signal, means responsive to fuel valve motion in the direction to increase fuel input to provide a temperature anticipating signal, and limiter means for restricting the amount of the increase in fuel input with relation to the speed error signal, such that the anticipating signal is effective to prevent excessive fuel input until such time as the temperature limiting signal assumes control of the fuel input to the engine to prevent development of excessive temperatures.

20. Apparatus as set forth in claim 17 characterized by provision of positive limiter means for restricting the magnitude of the temperature error signal in a positive direction, and negative limiter means for restricting the magnitude of the temperature error signal in a negative direction, said positive limiter means serving to prevent underfueling of the engine under low speed operating conditions, and said negative limiter means serving to prevent overfueling of the engine under high speed conditions.

21. In a jet engine having a variable area jet nozzle provided with a movable member and a fuel valve having a member movable to vary the fuel input, the combination of, an alternator driven in direct relation with engine speed; thermocouple means located to measure turbine discharge temperature; frequency sensitive means responsive to alternator output frequency; a first manually-adjustable voltage means to provide a speed setting; speed comparison means to provide a positive speed error signal when the engine speed as indicated by the frequency sensitive means is greater than the manual speed setting; reference means having a voltage output corresponding to a set maximum temperature; temperature comparison and amplifying means whose output is positive when the thermocouple E. M. F. is greater than the reference voltage; a second manually-adjustable voltage means to provide a temperature setting; a second temperature comparison means to provide a positive temperature error signal when the engine temperature as indicated by the comparison and amplifying means is greater than the manually set temperature; electric means for controlling the movable fuel valve member in response to speed and temperature signals such that the fuel input to the engine tends to decrease when either the speed error signal, the

temperature error signal, or the output of the comparison and amplifying means is positive; electric feedback means responsive to the motion of the fuel valve movable member to control the effect of said signals on the said electric control means; electric means for controlling the exhaust nozzle movable member in response to speed and temperature signals, such that the area of the jet nozzle area will be decreased when the speed error signal is positive or when the temperature error signal is negative; and electric feedback means responsive to motion of the exhaust nozzle movable member to control the effect of the last-named error signals on the last-named electric control means.

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