Jan. 22, 1957 T. J. THOMPSON 2,778,191

TAIL PIPE OF AFTERBURNING CONTROL FOR TURBOJET ENGINES

Filed June 3, 1948

3 Sheets-Sheet 1

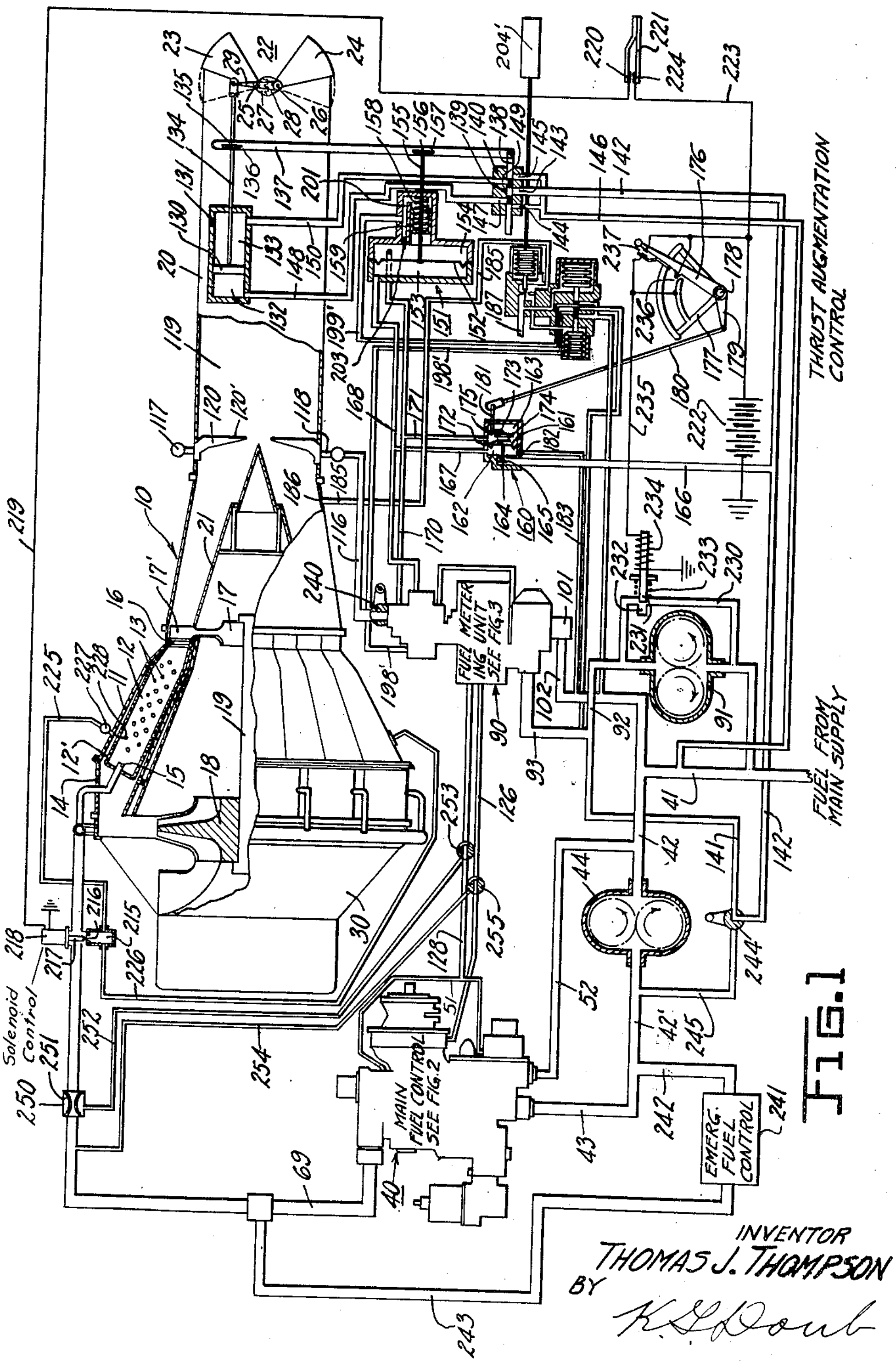

FIG. 1

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TAIL PIPE OF AFTERBURNING CONTROL FOR TURBOJET ENGINES

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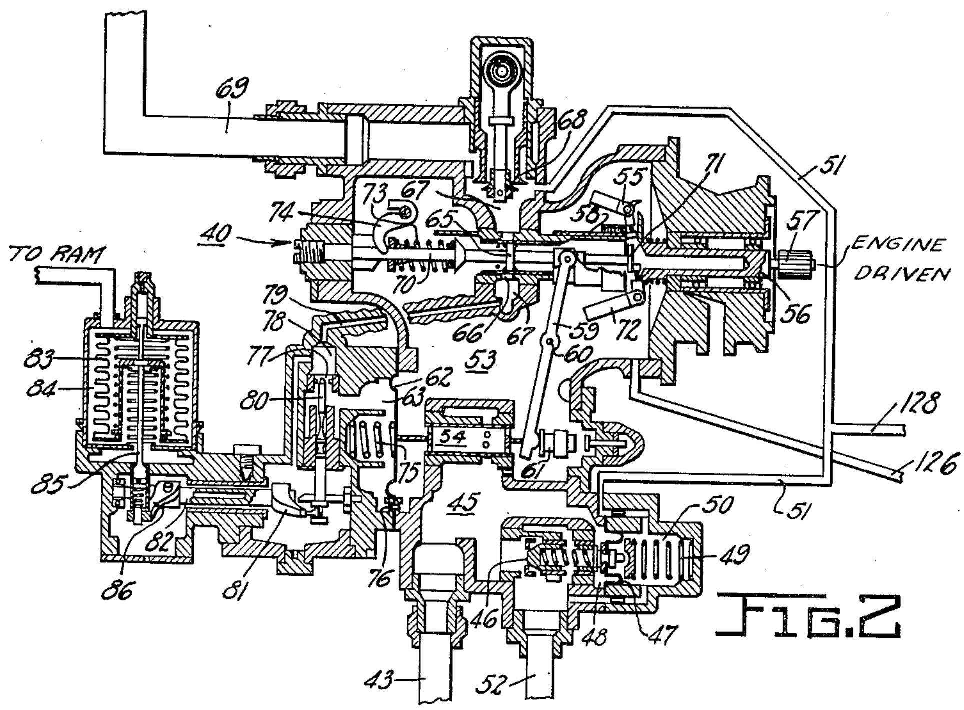

FIG. 2

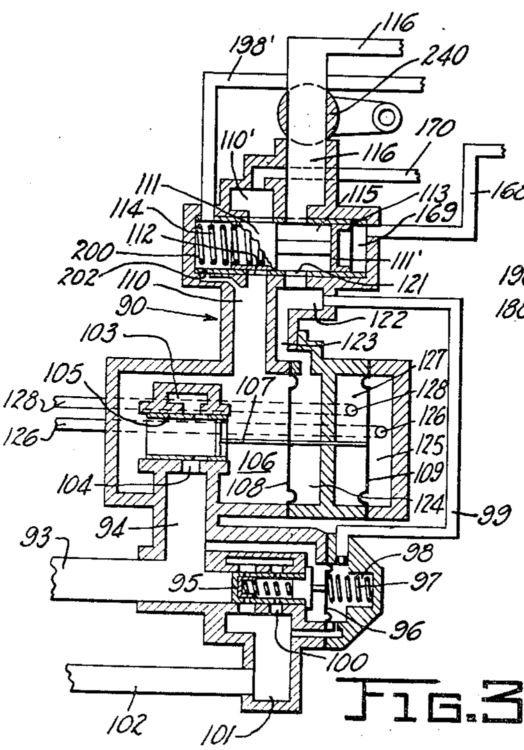

FIG. 3

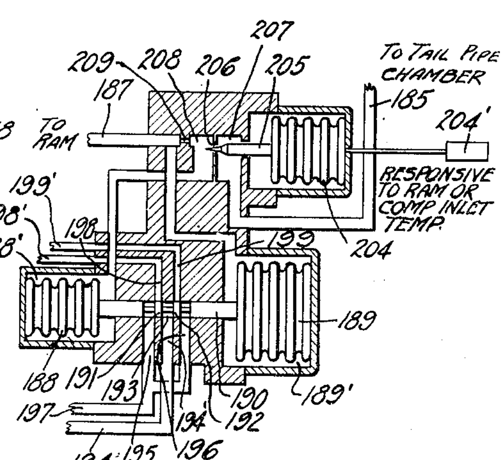

FIG. 4

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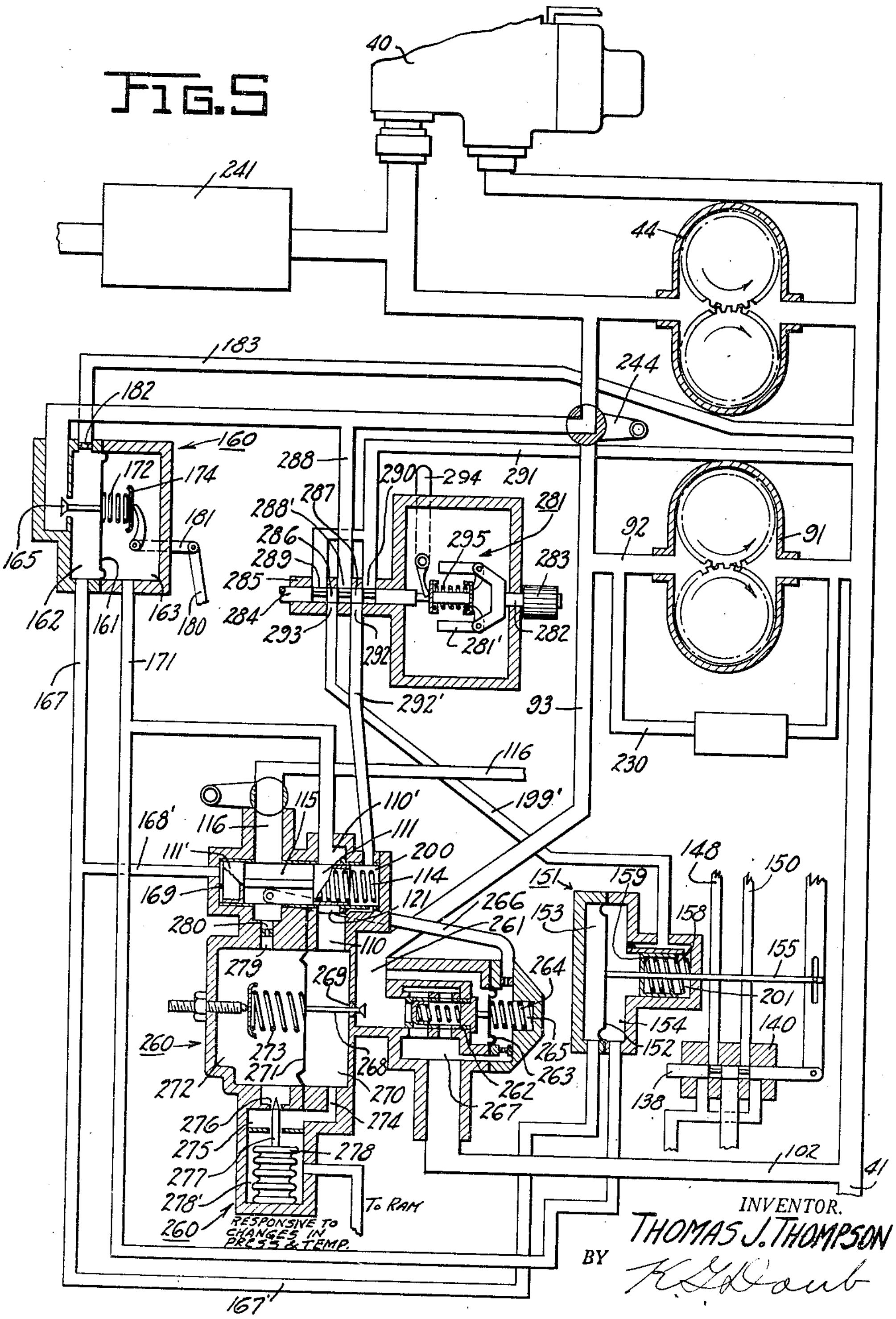
FIG.5



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2,778,191

TAIL PIPE OR AFTERBURNING CONTROL FOR TURBOJET ENGINES

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Application June 3, 1948, Serial No. 30,828

19 Claims. (Cl. 60—35.6)

This invention relates to turbojet engines for aircraft, and is particularly concerned with means for obtaining thrust augmentation in such engines by burning fuel in the tail pipe or tail cone section of the engine. This method of obtaining thrust augmentation is commonly termed "tail pipe burning" or "afterburning"; in the following description and claims, the term "afterburning" will be more commonly used for the simple reason that it is the shorter or more condensed of the two terms, although perhaps less apt.

In such systems, a variable area reaction or nozzle jet is employed and it is desirable to coordinate the rate of feed of the afterburning fuel with the rate of change of the jet nozzle area for maximum engine thrust efficiency; and an object of the present invention is to provide improved means for accomplishing this result.

Other objects include:

To provide an afterburning system for turbojet engines wherein there is a minimum of interference with normal engine operation;

To provide improved means for insuring ignition of the afterburning fuel;

To coordinate the rate of feed of the afterburning fuel with the normal supply to the burners;

To provide improved means for operating the various controls hydraulically;

And to generally improve the efficiency and operating characteristics of afterburning systems for turbojet engines.

Certain features illustrated and described herein but not claimed form the subject matter of a copending application by Frank C. Mock, Serial No. 25,828, filed May 5, 1948, now Patent No. 2,736,166, common assignee.

In the drawings:

Figure 1 is a schematic view of a turbojet engine and coacting tail pipe or afterburning control in accordance with the invention;

Figures 2, 3 and 4 are enlarged views in sectional diagram of parts of Figure 1, namely the main fuel control, the afterburning fuel metering unit, and the jet nozzle area corrector; and

Figure 5 is a sectional schematic of a modification directed primarily to the means for coordinating jet nozzle area and fuel feed.

The turbojet engine shown more or less diagrammatically in Figure 1 and generally indicated at **10** includes a group of burner units or combustion chambers each made up of an outer casing **11** in which is mounted a flame tube **12**, the walls of which are formed with a series of openings **13** for admitting air thereinto from the space **12'**. A series of air adapters or headers **14** are detachably connected to the front end of the burner assembly to direct air under pressure to the space **12'**, where part of the air enters through the holes **13** and mixes with the fuel discharged from burner nozzles **15** (one for each flame tube) to effect combustion, the expanded air and products of combustion being discharged from the said tubes through stator blades **16** and turbine blades **17'**, the latter forming part of a turbine rotor **17**. A dynamic compressor is generally indicated at **18**; it is shown as being of the centrifugal type but may, of course, be of the axial flow type; it is driven from the turbine and is shown mounted on a shaft **19** common to the turbine rotor and compressor.

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Beyond the turbine is the tail pipe **20**; it carries a diffuser cone **21** at its entrance end and other parts to be described, and at its outlet end terminates in a reaction jet or jet nozzle **22**, the area of which is adjustable by means of a pair of gate valves **23** and **24** mounted on suitable bearings such as trunnions or short shafts **25** and **26**. Also secured on said shafts are intermeshing segmental gears **27** and **28**. An arm **29** is secured at one end on the shaft **26** and at its opposite end is connected to a servo piston which is operated in a manner to be described.

The various accessories which go to make up the complete power plant are usually mounted at the front of the engine and in part housed by a suitable streamlined casing **30**. To more clearly bring out the features of the invention, however, the afterburning fuel metering system and coacting controls are removed from the housing and illustrated diagrammatically in operative relation to the engine **10**.

Since in Figure 1 the main fuel supply system is (as an alternate form) functionally related to the afterburning fuel metering device, sufficient parts of the main fuel control, indicated at **40** in Figure 1, are shown in sectional diagram in Figure 2 to provide an operative device. This device is, however, similar to that shown in a copending application of Frank C. Mock, Serial No. 716,154, filed December 13, 1946, and for a more detailed showing and description thereof, reference may be had to said application. Briefly, fuel is supplied to the device by way of conduits **41**, **42** (see Figure 1), **42'** and **43**, the fuel being maintained under pressure by fuel pump **44**. Fuel enters chamber **45**, see Figure 2, where its maximum pressure is determined by a relief or by-pass valve **46** having connected thereto a diaphragm **47**, the latter being subjected on one side to incoming fuel pressure at chamber **48** and on its opposite side to the force of a substantially constant rate spring **49** in chamber **50** plus metered fuel pressure by way of conduit **51**. Thus, valve **46** will open when the pressure in chamber **45** increases to a predetermined value above metered fuel pressure as determined by spring **49** and by-pass fuel back to the low pressure side of pump **44** by way of conduit **52**.

From chamber **45**, Figure 2, fuel flows to chamber **53** across regulator valve **54**. This valve is positioned as a function of engine speed and entering air density; its purpose is primarily to maintain a metering head across the throttle valve which varies with variations in engine speed, so that during acceleration of the engine, irrespective of how quickly a pilot or operator may open the throttle valve, the rate of fuel feed will be maintained within a predetermined upper limit to prevent dangerously high burner temperatures. When the engine is in operation, the valve **54** is urged in a valve opening direction by means responsive to changes in engine speed; in this instance by a centrifugal governor **55** which is mounted on a hollow shaft **56** having a drive pinion **57** secured on the outer end thereof adapted to be driven from the engine. The governor **55** is operatively connected to the valve **54** by means of a sliding sleeve **58** and lever **59** pivoted or fulcrumed at **60**. It its lower end, lever **59** engages a member **61** secured on the adjacent end of the stem of valve **54**. The opposite end of the said stem is connected to a diaphragm **62** having on one side the chamber **53** and on the opposite side a chamber **63**.

A throttle valve is shown at **65**, it controls a metering restriction **66** through which fuel may flow from chamber

53 to chamber 67 and thence across fuel shut-off valve 68 to metered fuel conduit 69. The throttle valve 65 is secured on a slidable rod or shaft 70 which at its inner or right-hand end carries a contact head or disc 71 engaged by a centrifugal governor 72 rotatable with the engine driven shaft 56. As this governor swings outwardly with an increase in engine speed, it tends to slide rod 70 to the left and close valve 65 against the tension of a governor spring 73, the latter being adjusted manually from the pilot's cockpit by suitable control linkage, including lever 74.

When the pilot wishes to accelerate, he moves lever 74 to the right or counterclockwise. This opens the throttle valve 65 and simultaneously sets the governor spring 73. The engine now speeds up due to an increase in the area of the feed restriction 66 and a corresponding increase in the rate of fuel feed. However, the speed of the engine cannot increase faster than a predetermined rate due to the fact that the metering head across the throttle valve is determined by the regulator valve 54, which in turn is positioned as a function of engine speed. When the governor 72 balances the setting of the governor spring 73, an equilibrium condition is attained and the engine operates at a steady speed. To decelerate, the pilot rotates lever 74 to the left or clockwise, whereupon the reverse of the foregoing ensues. The spring 75 in back of the regulator diaphragm 62 is for maintaining a minimum metering head; it has little effect on fuel flows above idle.

Upon a decrease in the density of the air flowing to the engine, less fuel is required to drive a turbine and compressor at a given speed, and unless the maximum rate of fuel delivered to the burners during acceleration is correspondingly reduced, much higher burner temperatures will be experienced during acceleration at altitude than would be the case at sea level under similar engine conditions. A density control circuit is therefore provided; it comprises a control jet or fixed flow orifice 76 between the chambers 53 and 63, a variable orifice 77 through which the fuel must pass from chamber 63 to a chamber 78 and thence by way of a duct or pasage 79 to the metered fuel chamber 67. The orifice 77 is controlled by a needle valve 80 which at its lower end is connected to a lever or arm 81 secured on the inner end of a shaft 82, rotatable in response to movement of a capsule or bellows 83, mounted in a chamber 84 vented to ram pressure and temperature and having its movable end connected by means of a rod or link 85 with a lever 86 secured on the outer end of the shaft 82. The bellows or capsule 83 is loaded to render it responsive to changes in both pressure and temperature, see Patent No. 2,376,711 to Frank C. Mock for a method of loading a bellows for such service. Expansion of the bellows (decrease in density as by a gain in altitude) moves the needle 80 downwardly and enlarges the area of orifice 77; and contraction of the bellows (increase in density) has the opposite effect. It will be seen that the duct or passage 79 by-passes the throttle valve 65.

For a given engine or turbine speed, the differential across the metering head diaphragm 62 will be constant, and hence the flow through the control jet 76 will remain constant. All flow of fuel through the jet 76 will pass through the variable orifice 77 in series therewith, and hence the drop across the latter orifice will vary as the square of its area; and for a fixed or given position of the needle 80 (constant density) the drop across the variable orifice 77 will be proportional to the drop across the control jet 76. The sum of the drop across the variable orifice 77 and the drop across the diaphragm 62 (or jet 76) is substantially equal to the drop across the governor valve 65, and at a given density, the total drop will be proportional to the square of engine speed. If the effective area of orifice 77 is enlarged, there will be a corresponding decrease in the drop across this orifice and a reduction in head across the governor valve 65, resulting in a diminishing flow of fuel to and through the conduit 69 and hence to the burner nozzles for a given area of the feed restriction 66. Thus, if the governor valve is opened for acceleration at a given altitude, less fuel will be supplied to the burners than would be the case at ground level or at some lower altitude.

The afterburning or tail pipe fuel is metered by the device indicated generally at 90 in Figure 1 and shown in sectional diagram in Figure 3. A fuel pump 91, Figure 1, has its low pressure or inlet side arranged to receive fuel from conduit 41 and deliver it under pressure through conduits 92 and 93 to chamber 94, Figure 3, at the intake or receiving end of the device 90. Fuel in the chamber 94 is maintained at a predetermined pressure over and above metered fuel pressure by means of a by-pass or relief valve 95 having a stem connected to a diaphragm 96 backed by a substantially constant rate spring 97 located in a chamber 98, the latter being vented to metered fuel pressure by way of a conduit 99. Should the pressure in the chamber 94 increase beyond a predetermined value, the valve 95 opens and by-passes fuel back to the low pressure conduit 42 (Figure 1) by way of ports 100, chamber 101 and conduit 102. Thus, the valve 95 sets up the pressure drop across the entire device 90.

From the chamber 94, Figure 3, fuel flows into valve chamber 103 and thence through ports 104 across a regulator valve 105 into regulator chamber 106. The valve 105 is provided with a stem 107 which is connected to a pair of diaphragms 108 and 109 for a purpose to be described. From the chamber 106, the fuel flows by way of a passage 110 and valve chamber 110′ across a metering or throttle valve 111, shown in the form of a hollow piston, which controls the flow of fuel through metering restrictions 112 formed in a cylindrical sleeve 113, the said piston valve 111 being mounted to reciprocate in said cylinder. The piston valve 111 is connected by a stem or rod with a servo or actuating piston 111′, the function of which will presently be described. A spring 114 normally urges the pistons 111, 111′ in a valve closing direction, which is toward the right in Figure 3.

Metered fuel flowing through the restrictions 112 passes into chamber 115 and thence flows by way of conduit 116 to an afterburning fuel manifold 117, note Figure 1, whence it is discharged through any selected number of discharge nozzles 118 into the chamber 119 of the tail pipe 20. Each nozzle is preferably located directly in the lee of a diffuser or jet bar 120, formed with an active surface 120′ contoured in a manner such as to cause the fuel discharged thereagainst to adhere thereto and then spread laterally and also radially inwardly to the edges of the bar, where the fuel is caught by the gases flowing at high velocity through the tail pipe and diffused throughout the chamber 119. These bars not only serve to act as effective diffusers of the fuel, but they also permit the fuel manifold 117 and discharge nozzles 118 to be located exteriorly of the tail pipe out of the heat zone, thereby avoiding cracking and carbonization of any residual fuel which may remain in the manifold and nozzles after the tail pipe burning system is shut down, and which might otherwise result in clogging of the fuel system at this point. The said jet bars 120 are more fully illustrated and described in the copending application to Mock, Serial No. 25,828, heretofore noted; they form no part of the present invention.

Reverting now to Figure 3, the metered fuel in chamber 115 may also pass through port 121 into a chamber 122 and thence by way of passage 123 into chamber 124 on the right-hand side of the diaphragm 108. The diaphragm 108 is thereby subjected on the one side to the pressure of unmetered afterburning fuel and on its opposite side to the pressure of metered afterburning fuel, and the resultant differential is balanced against a similar fuel differential transmitted from the main fuel control 40 and applied across the diaphragm 109. Accordingly, unmetered fuel from chamber 53 of the main fuel control device is communicated to a chamber 125 on the one side of the diaphragm 109 by way of a conduit 126, and metered fuel is taken from the chamber 67 of the said main fuel control device by way of conduits 51 and 128 and applied to a chamber 127 on the opposite side of the diaphragm 109. By this means, the valve 105 automatically sets a metering head across the valve 111 proportional to the drop across the throttle valve 65 of the main fuel control, and since this drop is roughly proportional to air flow, the rate of feed of the afterburning fuel will also be generally proportional to air flow.

The position of the metering valve or piston 111 is coordinated with the action of the gate valves 23 and 24, Figure 1, and hence the area of the jet nozzle 22. Reverting to Figure 1, the tail gates or valves 23 and 24 are illustrated as being actuated by means of a servo piston 130 mounted in a cylinder 131, defining chambers 132 and 133 on opposite sides of the piston 130. The piston is connected to the lever 29 by means of a rod or link 134, the latter at an intermediate point being provided with a pin 135 which engages a slot 136 formed in the upper end of a servo lever 137, the latter extending downwardly and at its lower end being pivotally connected to a slide valve 138 provided with a valve land 139 slidable in a servo valve 140. Hydraulic operating fluid under pressure (in this instance fuel) is communicated to the valve 140 by way of conduits 141, 142 and port 143, the latter being formed in the body of the valve 140; and fluid is conducted to drain or other suitable low pressure area by way of ports 144 or 145 and conduit 146 leading back to the main fuel supply conduit 41. From valve 140, fluid under pressure may be communicated to the chamber 132 of the servo cylinder 131 by way of port 147 and conduit 148, and to the chamber 133 of said cylinder by way of port 149 and conduit 150.

The slide 138 of the servo valve 140 is positioned automatically in coordinated relation with the feed of fuel to the afterburning system by the jet nozzle area control device generally indicated at 151; it comprises a suitable casing having therein a diaphragm 152 which divides the casing into a pair of chambers 153 and 154. The diaphragm is connected to the servo lever 137 by means of a rod or link 155 and pin 156 engaging in a slot 157 formed in said lever. A spring 158, acting on a piston 159 connected to the rod or link 155, normally urges the diaphragm 152 and hence the valve land 139 to a neutral position where it closes the port 143. The function of the piston will subsequently be described.

A pilot's control regulator is generally indicated at 160; it comprises a suitable casing having therein a diaphragm 161 which divides the casing into chambers 162 and 163. A regulator valve 164 is connected to the diaphragm 161 and controls a port 165. Hydraulic fluid (in this instance fuel) under pressure flows to the chamber 162 by way of conduit 166 and valve port 165; and from the chamber 162 it flows by way of conduit 167 to conduit 168. The fluid in the conduit 168 is supplied equally in opposite directions to a chamber 169 defined in part by the hollow piston 111′ of the valve 111, note Figure 3; and is also applied to the diaphragm chamber 153 of the servo valve control 151, note Figure 1. Fuel under regulated pressure is taken from the chamber 110′ of the afterburning fuel metering device 90 and conducted to the chamber 163 of the small regulator 160 on the right-hand side of the diaphragm 161 by way of conduits 170 and 171, compare Figure 3 with Figure 1. The diaphragm 161 is backed by a spring 172 which is adjustable by means of a lever 173 acting on a plate 174, the said lever being secured on a shaft 175, see also Figure 5 wherein this construction is shown on a larger scale. A manual afterburning control lever 176 and associated quadrant 177 are provided, the said lever being secured on a shaft 178 which is operatively connected to

the shaft 175 by means of an arm 179, link rod 180 and arm 181. Chamber 162 is vented to the by-pass return conduit by bleed 182 and conduit 183.

To briefly explain at this point the operation of the prescheduled fuel metering and coordinated gate valve controls, when the manual control lever 176 is to the right as in Figure 1, the thrust effect of the spring 172 on diaphragm 161 is substantially zero, at which time the pressure in chamber 162 of the regulator unit 160, Figure 1, is substantially equal to the pressure in chamber 169 of the fuel metering unit 90, Figure 3. When the said spring is compressed by moving lever 176 to the left or counterclockwise, the valve 164 opens and (*a*) the pressure in chamber 169, Figure 3, increases, and this overcomes the force of the throttle valve spring 114, Figure 3, moving the throttle valve piston 111 to the left and correspondingly opening metering restriction 112, and (*b*) the pressure in chamber 153 of the jet nozzle area control device 151, Figure 1, simultaneously increases and moves diaphragm 152 to the right, opening port 143 of servo valve 140 and admitting fluid under pressure to conduit 148 and chamber 132, whereupon servo piston 130 moves to the right and opens gate valves 23 and 24. By properly calibrating the springs 114 and 158, a prescheduled rate of fuel feed and coordinated rate of change in jet nozzle area may be obtained.

Since both the rate of afterburning fuel feed and jet nozzle area are initially fixed by the interconnecting operating means just described, it may become necessary to adjust or correct the value of either or both factors at some engine operating condition, to insure maximum efficiency before and after the turbine. This corrective action is obtained by means responsive to changes from a preselected ratio of ram or compressor inlet pressure and tail pipe chamber pressure, such ratio preferably being selected on the basis of maximum thrust with 100% minimum jet nozzle area and no tail pipe burning. Referring to Figures 1 and 4, a conduit 185, Figure 1, receives tail pipe pressure at point 186, while a conduit 187 receives ram or compressor inlet pressure at a suitable location in the incoming air stream. A pair of pressure responsive bellows or capsules 188 and 189, having a predetermined balanced relation with one another, are mounted in chambers 188′ and 189′ and are interconnected by a slide valve 190 having lands 191 and 192 thereon, said lands being movable in a valve chamber 193. Fluid under pressure, in this instance fuel, is admitted to chamber 193 by way of conduit 194 and port 194′, while fuel to drain or a lower pressure source may escape from said chamber by way of ports 195 and 196 and conduit 197. When the servo valve lands 190 and 191 are displaced from a neutral position, they uncover ports 198 and 199, permitting fluid to flow by way of conduit 198′ to chamber 200 in back of the piston 111 of Figure 3, and also by way of conduit 199′ to chamber 201 in back of the piston 159 of the gate valve control unit 151 of Figure 1. The chambers 200 and 201 are provided with suitable bleeds 202 and 203 to permit proper functioning of the pistons 111 and 159. A temperature responsive device in the form of a bellows 204 is provided and is rendered responsive to compressor inlet temperature by means of a suitable thermal element 204′. The bellows 204 carries at its movable end a needle valve 205 which controls a variable orifice 206 between chambers 207 and 208. Air may escape from chamber 208 to ram or other lower pressure area by way of a bleed 209.

The bellows 188 and 189 are normally balanced against one another to hold the slide valve 190 in a neutral position for a predetermined ratio or differential between compressor intake or ram pressure and internal tail pipe pressure beyond the turbine, and should this ratio become unbalanced, the servo valve lands 190 and 191 will be displaced and modify the respective pressures in chamber 200, Figure 3, and/or chamber 201, Figure 1. This will result in either or both a change in the metering rate of the afterburning fuel and/or a change in the jet nozzle area. In this manner, it becomes possible to override the initially correlated afterburning fuel metering and jet nozzle area controls and obtain the required corrective action.

The temperature bellows 204 serves to maintain the ratio of tail pipe chamber to ram pressure constant. It does this by varying the effective tail pipe chamber pressure in bellows chamber 188′ as a function of entering air or compressor inlet temperature. Since the pressure drop across the compressor and turbine varies substantially with variations in entering air temperature, a preselected fixed ratio of pressures at the two points specified may be maintained under varying operating conditions by modifying the effective tail pipe pressure in proportion to changes in the entering air temperature.

To insure ignition of the afterburning fuel, means are provided for increasing the rate of fuel feed to any selected one or more of the burners **12** to project a spurt of flame outwardly through the turbine into the tail pipe chamber 119. This is done by unbalancing the fuel feed to the remaining burners. In this manner, the overall burner temperature and pressure is maintained at a given value even though the temperature and pressure in one or more selected ignition burners is increased during the ignition period. Referring to Figure 1, an ignition fuel chamber 215 is provided and may be communicated with the main fuel conduit 69 by way of a valve port **216**, controlled by a solenoid valve **217**, actuated by a solenoid **218**, the winding of the latter being electrically connected by means of a circuit wire **219** and contact **220** with a switch **221**. When the switch **221** is closed, current may flow from the positive terminal of a battery **222** by way of wire **223**, switch contacts **224** and **220**, and wire **219** to the coil or winding of solenoid **218**. Energization of the solenoid raises the valve **217** and opens port **216**, whereupon fuel may flow from the main fuel conduit 69 into the chamber 215. In Figure 1, the chamber **215** is shown as supplying two of the burners **12** with fuel by way of conduits **225** and **226**, fuel manifold **227** and nozzles 228. Since the ignition fuel is taken from the metered fuel conduit 69 of the main fuel control device which supplies fuel to the burners **12** at a constant rate for a given throttle position, there will be no increase in the rate of flow to the burner system and hence in engine speed when the valve **217** is opened and the ignition system is placed in operation. However, the temperature will rise in the ignition burners and each will project a spurt of flame outwardly into the area of the tail pipe chamber where the afterburning fuel is being discharged by the nozzles **118**. The switch **221** may be controlled either manually or automatically.

The afterburning system may be placed in operation by moving the manual afterburning control lever **176** to the left or counterclockwise, as heretofore noted, but it is preferred to have means for selectively rendering the afterburning fuel pump **91** effective to pressurize fuel to the fuel metering device or regulator **90**, the pilot's regulator device 160 and servo valves **140** and **190** prior to actually starting the afterburning system. Accordingly, the pump **91** has a by-pass line **230** controlled by a solenoid valve **231** adapted to engage in a seat **232**. A spring 233 normally urges the valve **231** toward open position; it is closed by energizing solenoid coil **234**, which is adapted to be connected to the positive terminal of battery **222** by wire **235** through parallel switches **236** and **237**. The switch **236** is of the sliding contact type, closing when the lever **176** is moved a predetermined distance toward the left from its ineffective position and remaining closed until said lever is turned back to such position; while the switch **237** may be used to close the circuit to solenoid coil **234** when the lever **176** is in its ineffective position and thus render the pump **91** effective to pressurize fuel to the devices **90** and **160** and servo valves **140** and **190** preparatory to placing the afterburning system in operation. Pump **91**, when by-pass valve **231** is open, puts very little additional load on the engine and hence may be driven continuously; it may, however, be driven only when the afterburning system is in operation, if desired.

The valve indicated at **240** is a positive cut-off for metered afterburning fuel; it may be used when the afterburning system is shut down and at other times for convenience in servicing.

An emergency fuel control is shown in block diagram at **241**; it by-passes the main control **40** through conduits **242** and **243**.

The valve indicated at **244** is a selector valve whereby main fuel pump pressure may be continuously applied to the various afterburning fuel controls and operating servo valves when the engine is in operation instead of only when the afterburning system is in operation or preparatory to placing the latter in operation. When this valve is turned clockwise 90° from the position shown, fuel under pressure may flow from the high pressure side of pump **44** to conduit **142** by way of conduit **245**.

Operation

Ordinarily, a thrust augmentation or afterburning system is not used until the maximum power available has been obtained by an advanced setting of the throttle of the normal fuel system. Thus, when the afterburning system is to be placed in operation, the throttle valve **65** of the main fuel control unit **40** would be in its high power position. When the pilot or operator desires to obtain thrust augmentation, he grasps the control lever **176** and closes the switch **237**, whereupon the solenoid valve **231** closes and the pump **91** operates to pressurize fuel to the chamber **94** of the control unit **90**, the throttle regulator **160** and the servo valves **140** and **190**. At about the same time, the pilot moves the lever **176** counterclockwise, whereupon (*a*) the switch **236** closes, holding the valve **231** closed; (*b*) the spring **174** of the pilot's control unit **160** is compressed and the valve **164** opens, permitting fuel to flow through conduit **167** to **168** from which it is applied equally to the chamber **169** on the right hand side of the piston **111** of Figure 3, and to the chamber **153** on the left hand side of the diaphragm **152** of the unit **151** of Figure 1. Fuel now flows across the piston valve **111**, Figure 3, and thence by way of conduit **116** to the afterburner fuel manifold **117**, Figure 1, from which it is delivered by the nozzles **118** into the tail pipe chamber **119** in lee of and in part against the active surfaces of the jet bars **120**; and simultaneously with this action, the diaphragm **152** moves to the right and opens servo valve **140** to permit fuel to flow to the chamber **132** of the servo cylinder **131**, Figure 1, and this causes the tail gate valves **23** and **24** to open and increase the jet nozzle area. As the pilot moves the afterburning control lever **176** into operative position, he may also close the ignition switch **221**, and this opens the solenoid valve **217** and permits ignition fuel to flow from the conduit **69** to chamber **215** and thence by way of conduits **225** and **226** and manifold **227** to the ignition burners, and a spurt of flame is projected outwardly through the turbine blades **17′** into the afterburning fuel in chamber **119**. Since the overall rate of fuel feed to the main burner system is not increased, the speed of the engine as well as the temperature of the main burner system will not be increased when the ignition fuel is supplied to the ignition burners.

Should the prescheduled rate of fuel feed and jet nozzle area tend to become unbalanced, the bellows 188 and/or **189** will become effective to move the servo valve **190** into a position where it will act on the piston valve **111** through conduit 198′ and/or on the piston 159 through conduit **199′**, in the manner heretofore specified.

To close off the afterburning system, the lever 176 is turned clockwise to a position such that the differential across the diaphragm **161** of the throttle control unit **160** is substantially zero, whereupon there is a reduction in pressure in the chamber **169** of the afterburning fuel metering unit of Figure 3, and the piston valve **111** closes, stopping the flow of fuel to the nozzles **118**, Figure 1; and at the same time the pressure in chamber **153** on the left-hand side of the diaphragm **152** of the device **151** of Figure 1 is also reduced, the spring **158** moves the servo valve piston **138** to the left, fuel under pressure flows to the chamber **133** of the servo cylinder or motor **131**, and the gate valves **23** and **24** are adjusted to the most effective jet nozzle area for normal engine operation. When the lever **176** is moved back to a non-operating position, the switch **236** opens and this in turn opens the by-pass conduit **230** of pump **91** and the load on the latter is reduced to a low value.

Instead of metering the afterburning fuel in proportion to the drop across the throttle valve **65** of the main fuel control **40**, it may prove desirable to meter such fuel in proportion to the rate of flow of fuel to the main burner system independently of the main fuel control. Means for effecting this latter function is shown as an alternate control in Figure 1; it consists in disposing a venturi meter **250** in the fuel line **69** having one or more orifices **251** formed in the constricted portion thereof and communicating with the conduit **128** by way of a conduit **252** and selector valve **253**. Another conduit **254** communicates pressure upstream of the venturi **250** with the conduit **126** through selector valve **255**.

In the position of the selector valves **253** and **255**, the venturi meter is closed off from the lines **126** and **128** and hence the differential across the diaphragm **109** of the afterburning fuel metering unit **90** of Figure 3 is proportional to the drop across the throttle valve **65** as heretofore described. However, by turning the selector valves roughly about 90° anticlockwise, the conduits **252** and **254** will be communicated with the conduits **126** and **128** and the latter will be closed off from the main fuel control unit **40**. The differential across the diaphragm **109** then becomes proportional to flow of fuel through the conduit **69** squared.

In a gas turbine compressor engine, airflow is proportional to engine speed, and the force set up by the engine driven governor **55** of the main fuel control **40** of Figure 2 is proportional to engine speed squared. This force is therefore proportional to airflow squared and is used to set up a head across the variable metering restriction **66**. Since the fuel flow through said restriction is proportional to the square root of the head, fuel flow as regulated and as corrected for changes in density becomes proportional to air flow. Hence, in both methods of producing a differential across the diaphragm **109** of the after-burning fuel regulator and metering device **90** of Figure 3, fuel flow to the afterburning nozzles **118** is rendered substantially proportional to air flow. An advantage of the venturi meter arrangement is that it may be used with the emergency control **241**, which is not the case when the drop across the throttle valve **65** is taken as the controlling differential. If the emergency control has a correction for changes in density, fuel flow would still be proportional to air flow.

Figure 5 illustrates a modification in the afterburning system with respect to that shown in Figure 1. In the arrangement of Figure 5, the means for coordinating the rate of fuel feed and jet nozzle area operates as a function of engine speed. Also, there is a separate fuel regulator and metering device for the afterburning fuel, which renders the afterburning fuel system independent of the main fuel control.

The parts in Figure 5 which correspond to like parts shown in Figures 1 to 4, inclusive, are given corresponding reference numerals, and need no further description.

The afterburning fuel pump **91** is controlled in the same manner as in Figure 1; it delivers fuel to input chamber **261** of an afterburning fuel regulator unit **260**, the metering and throttle control section of which is substantially similar to corresponding parts of the unit **90** of Figures 1 and 3. The delivery pressure of the fuel in chamber **261** is maintained at a constant predetermined value over and above metered fuel pressure by means of a by-pass piston type valve **262** having its stem connected to a diaphragm **263** backed by a spring **264** in a chamber **265**, the latter being vented to the fuel metered fuel chamber **115** by way of conduit **266**. When the pressure in chamber **261** exceeds a predetermined value over and above metered fuel pressure as determined by the spring **264**, the valve **262** opens and by-passes fuel into chamber **267** and thence by way of conduit **102** back to the low pressure side of the pump **91**. A regulator valve is indicated at **268**; it controls a port **269** through which fuel may flow from chamber **261** into chamber **270**. A diaphragm **271** forms a movable wall between the chambers **270** and **272**. The diaphragm is backed by a substantially constant rate spring which maintains a substantially constant differential across said diaphragm. When the throttle valve or piston **111** is opened, fuel flows from chamber **270** through metering restriction **121** across said piston valve and thence by way of conduit **116** to the afterburning fuel nozzle **118** of Figure 1. Since the diffferential across the diaphragm **271** is maintained substantially constant, the flow of fuel to the afterburner nozzles will remain substantially constant for any given position of the piston valve **111**.

Since less fuel is required to maintain a given thrust or power output as the density of the air flowing to the engine decreases, it is desirable to provide density compensation for the afterburning fuel. This is done in the regulator **260** of Figure 5 by means of a density circuit and coacting parts including passage **274**, valve chamber **275**, variable orifice **276** controlled by needle valve **277** carried by the movable end of a bellows or capsule **278**, responsive to changes in pressure and temperature and therefore density, and passage **279** having a bleed **280** therein. Bellows **278** is located in a chamber **278′** vented to ram or compressor inlet pressure and temperature. Fuel flowing through this density circuit by-passes the metering restriction **121**. It will be seen that at normal ground level pressures and temperatures, the bellows **278** will be in its collapsed position, at which time the variable orifice **276** will be of maximum area. There are in effect two flow passages in parallel from the port **269** to metered fuel passage **116**; the one consisting of chamber **270** and feed restriction **121**, and the other comprising passage **274**, valve chamber **275**, variable orifice **276**, chamber **272**, passage **279** and bleed **280**. The regulator **260** functions to establish a pressure in chamber **270** which is greater than that in chamber **272** by the pressure value of spring **273**. The diaphragm **271** and spring **273** maintain a constant differential across variable orifice **276**, and hence the flow through said orifice will increase and decrease as valve **277** opens and closes. Since all flow of fuel through variable orifice **276** must also flow through fixed orifice **280**, the head across the latter will increase or decrease upon opening or closing of valve **277**. Thus as bellows **278** expands in response to a decrease in the density of the air flowing to the engine and valve **277** progressively restricts orifice **276**, the head causing flow across feed restriction **121** will correspondingly decrease, resulting in a reduction in flow of fuel to the nozzles **118** for a given position of piston valve **111**.

A speed governor is generally indicated at **281**. It comprises a series of weights **281′** rotatable with a shaft **282** provided with a pinion **283** adapted to be driven from the engine. A servo valve **284** is connected to the governor **281** and is mounted to slide in a valve casing **285**. The valve **284** is provided with lands **286** and **287**. Fluid under pressure, in this instance fuel, flows to the valve casing **285** by way of conduit **288** and port **288′**, and fluid is released to drain by way of ports **289** and **290** and conduit **291**. Fuel under pressure may flow to the chamber 200 in back of the piston 111 by way of port 292 and conduit 292', and fuel under pressure may also flow from the valve casing 285 to the chamber 201 of the jet nozzle area control device by way of port 293 and conduit 199'. The governor 281 is preferably adjustable by means of a lever 294 acting on governor spring 295.

In operation, the pilot compresses the spring 172 of the auxiliary thrust throttle regulating unit 160 in the same manner as described in connection with Figure 1, opening valve 165 and permitting fuel under pressure to flow into chamber 162 and thence by way of conduits 167 and 168' to the chamber 169 in back of the piston 111', whereupon the latter, together with piston 111, moves to the right against the resistance of the spring 114 and opens the metering restriction 121; and at the same time fuel under pressure also flows by way of conduit 167' to the chamber 153 of the device 151, opening the servo valve 138 and permitting fuel to flow by way of conduit 148 to the gate valve servo piston 131 of Figure 1 and open the gate valves 23 and 24.

In explaining coordination of the rate of fuel feed and jet nozzle area by means of a device operating as a function of engine speed, let it be assumed that the turbine is operating on the normal burner system (no tail pipe burning) with the area of the jet nozzle set for 100% efficiency. If now the gate valves were opened and this area increased, there would be an increase in engine speed due to the fact that there would be a higher drop across the turbine. On the other hand, should the jet nozzle area be reduced due to closing of the gate valve, the overall drop across the engine would be decreased and there would be a corresponding decrease in engine speed. Using this as a basis for correlating jet nozzle area and rate of afterburning fuel feed, it will be seen that there will be a like variation in engine speed should the area of the jet nozzle be increased at a rate faster than a predetermined or prescheduled rate, and there would be a corresponding variation in engine speed should the jet nozzle area be decreased faster than a prescheduled rate.

In the position of the governor 281 shown in Figure 5, it can be assumed that the engine is operating with jet nozzle area and rate of fuel feed in coordinated relation, since at this time the servo valve 284 is in a position such that the valve lands 286 and 287 block the ports 292 and 293. If now the engine speed should vary from its prescheduled coordinated rate with respect to fuel feed and jet nozzle area, the servo valve 284 will become displaced from its closed position and vary the pressures in either the chamber 200 of the fuel metering unit or in the chamber 201 of the device 151 and adjust the fuel feed and/or jet nozzle area to their prescheduled values.

Although only two embodiments of the invention have been illustrated and described, various changes in the form and relative arrangement of the parts may be made to suit requirements.

I claim:

1. In a system for obtaining thrust augmentation in a turbojet engine by burning fuel in a chambered area after the turbine in addition to the fuel supplied to the burners before the turbine, a main fuel control having a variable feed or metering restriction and means for maintaining a metering head across said restriction as a function of engine speed, an afterburning fuel control also having a variable feed or metering restriction, and means interconnecting said controls whereby the differential across the metering restriction of the afterburning fuel control is maintained proportional to the drop across the metering restriction of the main fuel control.

2. In a system for obtaining thrust augmentation in a turbojet engine by burning fuel in a chambered area after the turbine in addition to the fuel supplied to the burners before the turbine, a main fuel control having a variable feed or metering restriction and means for maintaining a head across said restriction varying with variations in engine speed, an afterburning fuel control also having a variable feed or metering restriction, and means including a regulator valve and coacting pressure responsive means such as a diaphragm subjected to the drop across the metering restriction of the main fuel control.

3. In a system for obtaining thrust augmentation in a turbojet engine by burning fuel in a chambered area after the turbine in addition to the fuel supplied to the burners before the turbine, a main fuel control for metering fuel to said burners, a metered fuel conduit for connecting said fuel control to the burners, an afterburning fuel control having a variable metering restriction, and means for maintaining a head across said restriction responsive to variations in the flow of fuel through said conduit.

4. In a system for obtaining thrust augmentation in a turbojet engine by burning fuel in a chambered area after the turbine in addition to the fuel supplied to the burners before the turbine, a main fuel control for metering fuel to said burners, a conduit for metered fuel, an afterburning fuel control provided with a variable metering restriction, and means for maintaining a fuel head across said restriction including a fuel head regulating valve and coacting pressure responsive means for controlling said valve subjected to a differential pressure varying with variations in the flow of fuel through said conduit.

5. In a system for obtaining thrust augmentation in a turbojet engine by burning fuel in a chambered area after the turbine in addition to the fuel supplied to the burners before the turbine, a main fuel control for metering fuel to said burners, an emergency fuel control system arranged to by-pass said main fuel control, a conduit for metered fuel common to both controls, an afterburning fuel control having a variable metering restriction, and means for maintaining a metering head across said latter restriction varying with variations in the flow of fuel through said conduit.

6. In a system for obtaining thrust augmentation in a turbojet engine by burning fuel in a chambered area after the turbine in addition to the fuel supplied to the burners before the turbine and adjusting the area of the jet nozzle to obtain maximum thrust for a given overall rate of fuel feed; an afterburning fuel control device having a variable metering restriction and a throttle valve controlling the area of said restriction, first fluid pressure responsive means for operating said throttle valve, second fluid pressure responsive means for varying the area of the jet nozzle, and means under the control of a pilot or operator for controlling the application of an operating fluid to at least one of said fluid pressure responsive means.

7. In a system for obtaining thrust augmentation in a turbojet engine by burning fuel in a chambered area after the turbine in addition to the fuel supplied to the burners before the turbine and adjusting the area of the jet nozzle to obtain maximum thrust for a given overall rate of fuel feed; an afterburning fuel control device having a variable metering restriction, a hydraulically operated throttle valve for controlling the area of said restriction, hydraulically operated means for varying the area of the jet nozzle, a device for regulating the flow of hydraulic fluid to said throttle valve and said area varying means, and means for maintaining a prescheduled rate of fuel feed and jet nozzle area.

8. A system for obtaining thrust augmentation as claimed in claim 7, wherein said last named means includes a device responsive to variations from a predetermined ratio of compressor inlet pressure and the pressure in said chambered area after the turbine.

9. A system for obtaining thrust augmentation as claimed in claim 7, wherein said last named means includes a device which operates as a function of engine speed.

10. In a system for obtaining thrust augmentation in

a turbojet engine by burning fuel in the tail pipe section after the turbine in addition to the fuel supplied to the normal burner system before the turbine and adjusting the area of the jet nozzle to obtain maximum thrust for a given overall rate of fuel feed; an afterburning fuel control device having a variable metering restriction, a hydraulically operated throttle valve for varying the area of said restriction, a valve member for varying the area of the jet nozzle, a hydraulic motor for operating said valve member, a servo valve for controlling the flow of operating fluid to said motor, a pressure responsive device for controlling said servo valve, and means for subjecting said throttle valve and said device to hydraulic operating pressure in predetermined proportion to obtain a prescheduled rate of fuel feed and jet nozzle area.

11. In a system for obtaining thrust augmentation as claimed in claim 10 wherein there is a manually operable device for regulating the admission of hydraulic pressure to said throttle valve and said pressure responsive device.

12. In a system for obtaining thrust augmentation as claimed in claim 10, wherein there are means responsive to variations from a given ratio of compressor inlet pressure and the pressure in the chambered area after the turbine for subjecting said pressure responsive device to a corrective action.

13. In a system for obtaining thrust augmentation as claimed in claim 10 wherein there is a device responsive to changes in engine speed for subjecting the application of hydraulic operating pressure to said throttle valve and said pressure responsive device to a corrective action.

14. In a system for obtaining thrust augmentation in a turbojet engine by burning fuel in a chambered area of the tail pipe section after the turbine in addition to the fuel supplied to the burners before the turbine and adjusting the area of the jet nozzle to obtain maximum thrust for a given overall rate of fuel feed; a nozzle arranged to discharge fuel into said tail pipe chamber, a fuel control device for supplying fuel to said nozzle, said device being provided with a variable feed restriction and a hydraulically operated throttle valve for controlling the area of said restriction, a valve member for varying the area of the jet nozzle, a hydraulic motor for actuating said valve member, a servo valve for controlling the flow of hydraulic fluid to said motor, a pressure responsive element operatively connected to said servo valve, a throttle regulator for controlling the flow of fluid to said throttle valve and said element, and means for coordinating the action of said throttle valve and said element to obtain a prescheduled rate of fuel feed and jet nozzle area.

15. In a system for obtaining thrust augmentation in a turbojet engine as claimed in claim 14 wherein there is a device responsive to changes from predetermined ratio of compressor inlet pressure and tail pipe chamber pressure which acts to modify the effective action of said throttle valve and/or element should the rate of fuel feed and jet nozzle area vary from a prescheduled coordinated relation.

16. In a system for obtaining thrust augmentation in a turbojet engine by burning fuel in a chambered area after the turbine in addition to that supplied to the normal burner system before the turbine, a fuel control device for supplying afterburning fuel to said chambered area, and means for igniting the afterburning fuel comprising means for increasing the quantity of fuel supplied to one or more but not all of the burners without varying the overall quantity of fuel supplied to all of the burners to cause a spurt of flame to be projected outwardly through the turbine into said chambered area without any substantial variation in engine speed.

17. In a system for obtaining thrust augmentation in a turbojet engine by burning fuel in a chambered area of the tail pipe section after the turbine in addition to the fuel supplied to the normal burner system, a main fuel control for the normal burner system, a conduit for conducting metered fuel from said main fuel control to the burners of the said burner system, means for supplying afterburning fuel to said tail pipe chamber, and means for igniting the fuel in said chamber comprising a selectively operable valve member and coacting flow conduit structure arranged to pass fuel from said metered fuel conduit to a selected burner of the main burner system constituting an ignition burner, to thereby maintain the overall burner supply constant while at the same time temporarily increasing the supply to the ignition burner and cause a spurt of flame to be projected outwardly into said chamber from the ignition burner without substantially affecting engine speed.

18. A system as claimed in claim 14 wherein said valve member is actuatable by an electric solenoid in circuit with a manually operable switch accessible to a pilot or operator.

19. A jet-engine combustion system having in combination an elongated combustion chamber, a main burner in the combustion chamber, a blower for supplying air under pressure to one end of the combustion chamber, a turbine at the other end of the combustion chamber, a jet pipe extending from the last mentioned end of the combustion chamber, an auxiliary burner in the jet pipe, means for supplying liquid fuel to the auxiliary burner, a liquid-operated servo-mechanism for determining the quantity of liquid fuel supplied to the auxiliary burner, control means responsive to the air pressure at the blower inlet, additional control means responsive to the gas pressure in the jet pipe between the turbine and the auxiliary burner, and a control member responsive to the combined action of the two control means for controlling the action of said servo-mechanism.

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