

April 10, 1956

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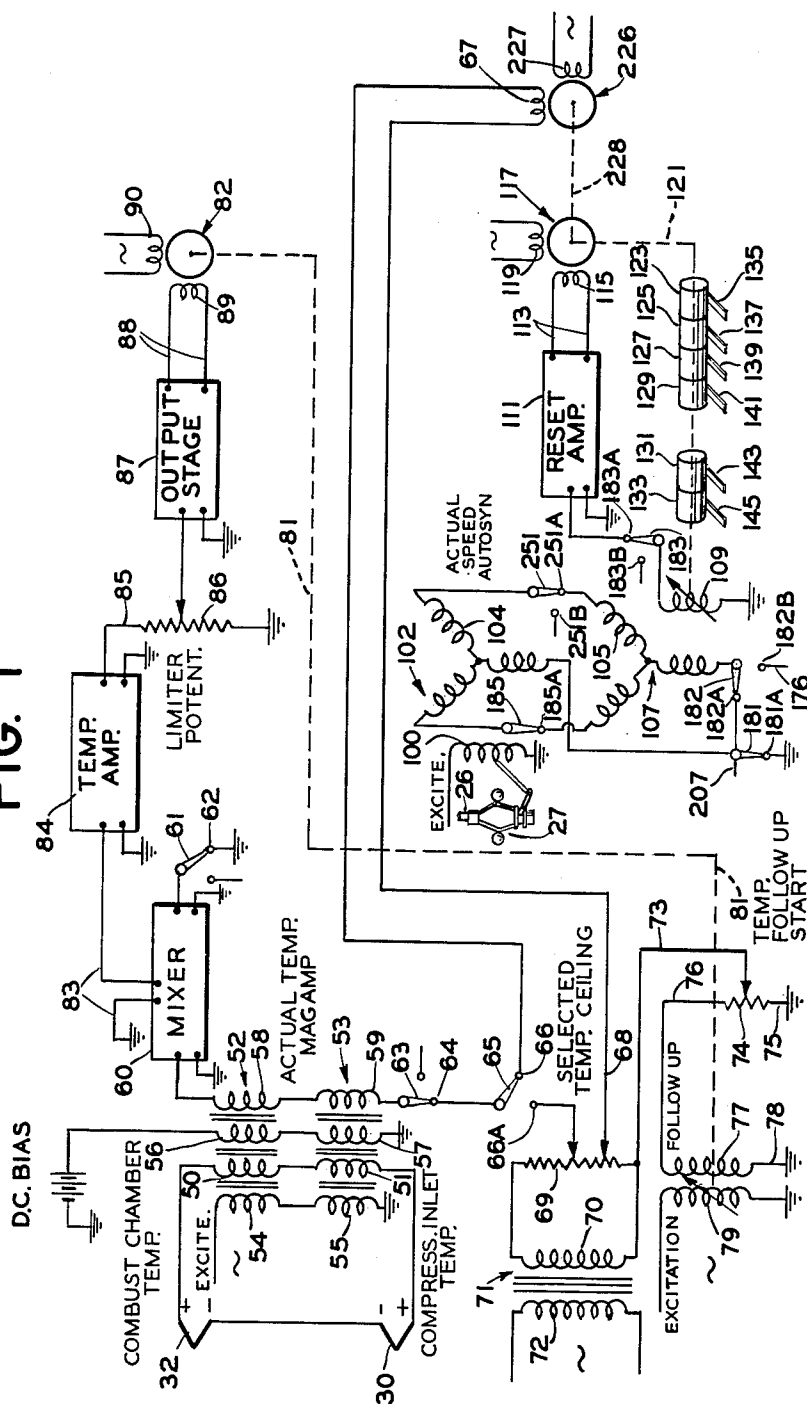
2,741,086

AUTOMATIC STARTER CONTROL

Filed April 26, 1950

4 Sheets-Sheet 1

FIG. 1



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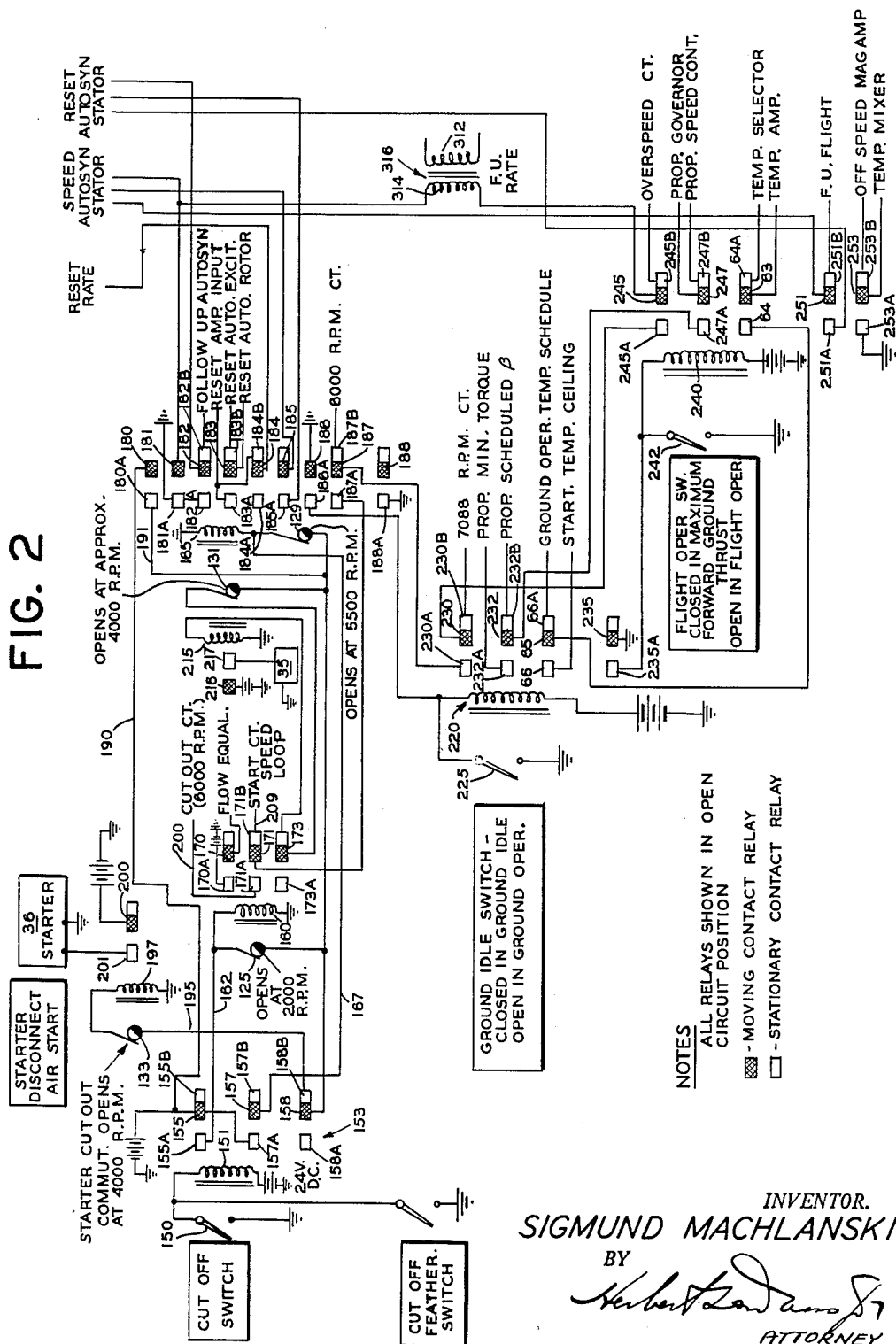
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FIG. 2



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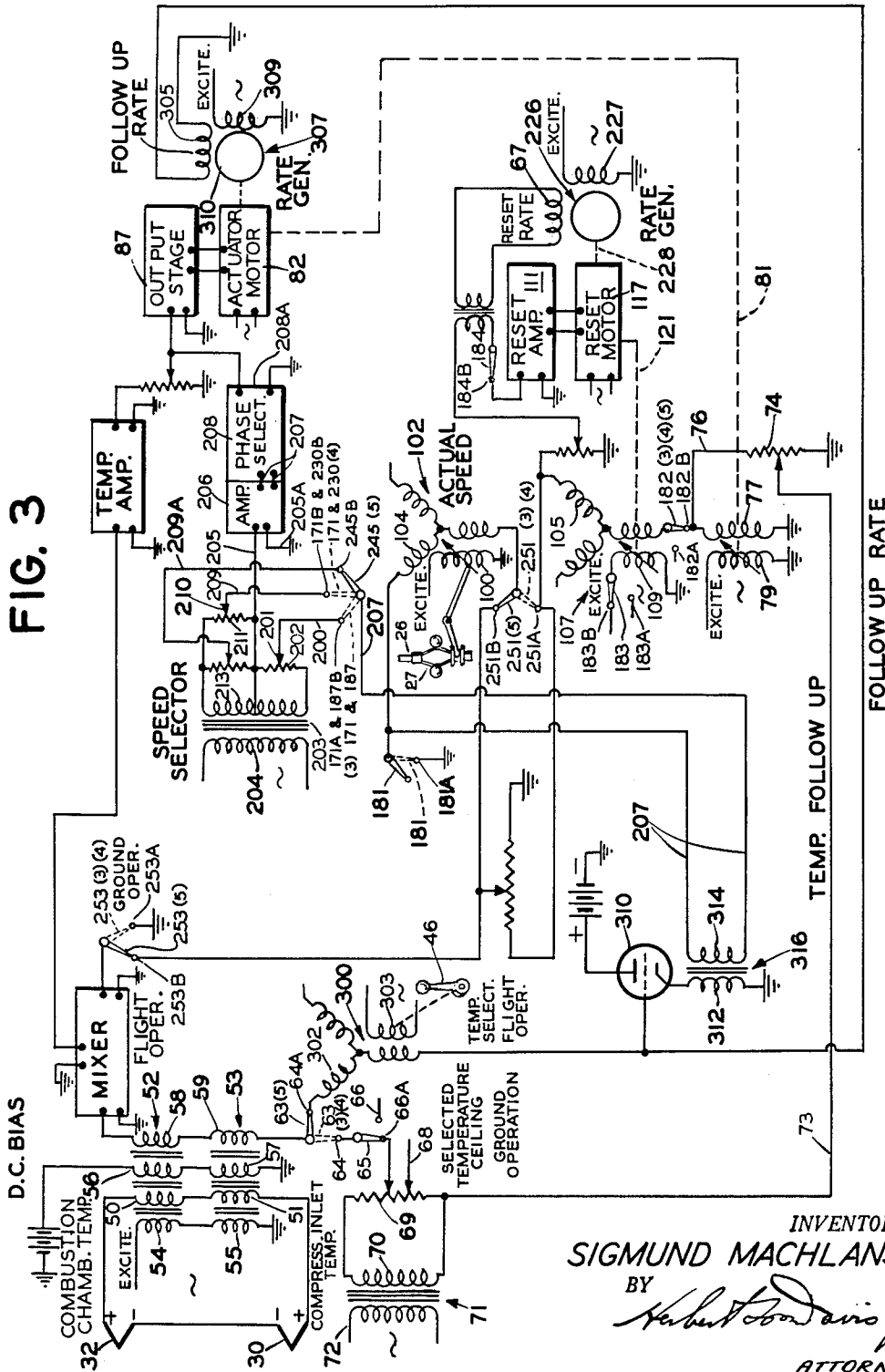
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AUTOMATIC STARTER CONTROL

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4 Sheets-Sheet 3

FIG. 3



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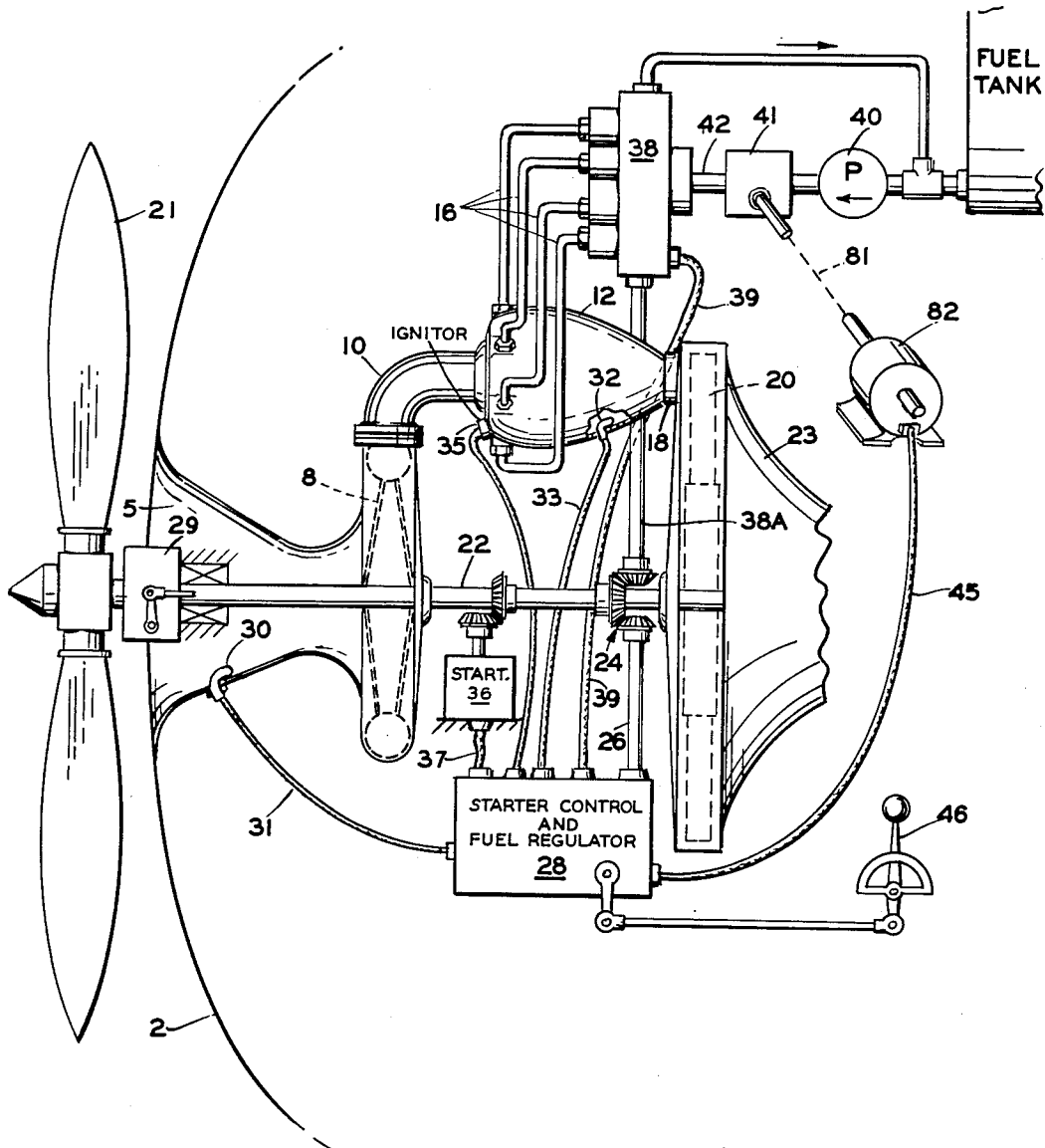
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4 Sheets-Sheet 4

FIG. 4



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2,741,086

AUTOMATIC STARTER CONTROL

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Application April 26, 1950, Serial No. 158,273

18 Claims. (Cl. 60—39.14)

The present application relates to improvements in an automatic starting control for a turbine driven aircraft engine.

In the copending application Serial No. 156,260 filed April 17, 1950 by William E. Brandau, there is disclosed and claimed an automatic starting control on which the subject matter of the present application involves certain improvements.

An object of the present application is to provide a speed sensing unit including a flyball governor and variable coupling transformer positioned by the governor and coupled to a reset variable coupling transformer positioned by a motor controlled by the first variable coupling transformer so as to act as a servo operated follower of speed and also including a series of switches operated by the servomotor to open and close suitable circuits controlling the starting operation as the sensed speed of the engine changes.

Another object of the invention is to provide an automatic starting control for a turbine engine which serves to actuate a series of switches in accordance with a prescribed schedule, these switches in turn operating various relays to initiate and terminate the several functions necessary in the starting of the engine.

Another object of the invention is to provide a novel automatic starting system in which the starting cycle cannot be reinitiated without first going back to cut off.

Another object of the invention is to provide an automatic control means for starting a turbine engine, including means for the initiation and termination of such necessary functions as the auxiliary drive to bring the engine up to a self-sustained speed and the ignitor and fuel supply to fire up the engine. Further, the control includes means to initiate the main supply of fuel to the engine and effect operation of a system to regulate the fuel supply so as to maintain a safe operating temperature and acceleration of the engine during the starting operation, until the turbine arrives at a selected self-sustained operating speed at which the control effects an automatic transfer from the first fuel regulating system to a second or primary fuel regulating system for normal operation of the engine.

Another object of the invention is to provide a novel speed sensing device to automatically effect the following functions:

1. Initiation of the operation of a suitable starting mechanism and the termination of such operation upon the speed of the engine reaching a predetermined value indicative that the engine is at a self-sustaining speed.
2. Initiation of the operation of an igniter and the termination of such operation upon the speed of the engine reaching a predetermined value indicative that the engine has been brought up to a self-sustaining speed.
3. Initiation of operation of the fuel supply to the engine upon the speed of the engine exceeding a predetermined minimum speed sufficient to effect a starting operation.
4. After initial starting of the engine is effected, the

2

temperature of the engine is controlled at a value sufficiently low to prevent compressor stall and sufficiently high to provide an accelerating torque on the engine throughout the starting cycle until at a predetermined engine speed a transfer is effected over to normal control of the engine by the aforementioned speed sensitive device.

Another object of the invention is to provide an automatic starter control in which the control regulates the fuel supply for a turbine engine so as to maintain a safe operating temperature during the starting operation and also regulates the rate of acceleration of the engine until the turbine speed reaches a selected operating speed at which an automatic transfer is effected to place the engine under control of a primary control system.

Another object of the invention is to provide an automatic control system in which such temperature control means is essentially the same as that of the primary control system and which makes use of a direct measurement of combustion chamber temperature so as to regulate the fuel supply through suitable means such as a variable displacement pump or regulating valve so as to maintain the selected temperature value.

Another object of the invention is to provide a novel acceleration feed back to reduce the selected temperature level with an increase in engine acceleration during the starting operation.

Since a characteristic of turbine engines is relatively poor efficiency at low speeds, a fixed operating temperature sufficiently high to guarantee acceleration of the engine at starting speed results in a runaway acceleration as the rated speed is approached and therefore an object of the invention is to provide an acceleration feed back which acts to moderate this tendency.

Another object of the invention is to provide an automatic starting device which employs a temperature control with acceleration feed back so that engine starts are more nearly uniform in character under severe changes in engine load or operating conditions.

Another object of the invention is to provide a system in which all the major components of the start control are parts of the primary control though serving entirely different purposes in the two phases of operation.

Another object of the invention is to provide a speed governor and variable coupling transformer assembly which provides the speed sense as the voltage signal in a primary control, while serving as a position transmitter to a servo operated variable coupling transformer in the starter control and in which the servo operated variable coupling transformer actuates suitable speed control switches for effecting the starting operation.

Another object of the invention is to provide an acceleration feed back in the starting control which is obtained from a generator arranged in the starter control to give a signal proportional to engine acceleration although during normal usage in the primary control the same rate generator provides a linear reset response as a function of an effective follow-up signal.

The above and other objects and features of the invention will appear more fully hereinafter from a consideration of the following description taken in connection with the accompanying drawings wherein one embodiment of the invention is illustrated by way of example.

In the drawings:

Figure 1 is a diagrammatic view showing a temperature responsive fuel control system for the automatic starting of a turbine driven engine in which there is provided a speed responsive mechanism for effecting the necessary accessory functions in the starting operations.

Figure 2 is a diagrammatic view showing the switching system for the automatic starter control operated by the speed responsive mechanism of Figure 1.

Figure 3 is a diagrammatic view showing the fuel control system for normal ground and flight operation.

Figure 4 is a diagrammatic view of an aircraft engine or gas turbine with which the systems shown in Figures 1, 2 and 3 are designed for use.

Referring to the drawing of Figure 4, there is indicated by the numeral 2 an aircraft of a type with which the subject invention is designed for use. The aircraft in flight moves toward the left as viewed in Figure 4 so that air is rammed into an intake 5. The ram air is in turn compressed by a blower or compressor 8 and flows through a conduit 10 into a combustion chamber 12. Fuel at a controlled rate is fed through lines 16 into the combustion chamber 12.

The products of combustion flow out through a nozzle 18 to drive a turbine 20 which drives the compressor 8 and a propeller 21 through a shaft 22. The exhaust exits through passage 23. Gearing 24 and a shaft 26 connect the shaft 22 with a flyball speed governor 27 of Figures 1 and 3 of the automatic starter control and fuel regulator 28 hereinafter explained.

The pitch of the propeller 21 may be governed by a suitable speed responsive governor 29 of a type well known in the art and under control of the pilot.

A temperature responsive device 30 sensitive to the temperature of the air at the intake 5 is operably connected through a conduit 31 to the fuel regulator for purposes hereinafter explained, while a temperature responsive device 32 is mounted at a suitable point in the combustion chamber 12 for sensing the temperature of the combustion gases. The device 32 is operably connected through a conduit 33 to the fuel regulator and starter control 28. A suitable ignitor 35 is provided for initially igniting the combustion gases in the chamber 12. The ignitor 35 may be of conventional type and is operably connected through a suitable electrical conduit to the starter control 28.

Also arranged for driving the turbine shaft 22 in starting is a suitable starting mechanism indicated herein generally by the numeral 36 and operably connected through conduit 37 to the starter control. The starting mechanism 36 may be arranged to engage the shaft 22 in driving relation during starting and disengage the shaft 22 after starting by suitable means, well known in the art.

The fuel input lines 16 may be controlled by a suitable fuel equalizer valve 38 of a type disclosed and claimed in my copending application Serial No. 158,274 filed April 26, 1950 and having maximum speed limiting means operatively connected to the shaft 22 through a shaft 38A as explained in the latter application.

The fuel equalizer valve 38 may be controlled by the automatic starter control 28 through an electrical conduit 39 operatively connected to the control 28. The equalizer valve 38 may be supplied with fuel under pressure of a pump 40 through a throttling valve 41 in a supply conduit 42.

The throttling valve 41 may be of conventional type operatively controlled through a shaft 81 by a reversible electric motor 82 connected through an electrical conduit 45 with the control system indicated generally by the numeral 35 and hereinafter explained with reference to Figures 1 and 3. Instead of a throttling valve, there may be used a variable displacement pump controlled by the motor 82 to vary the supply of fuel to the combustion chamber 12 in accordance with the demands of the regulator 28. A manual operable lever 46 may be adjusted by the pilot in flight to vary the setting of the regulator 28 to select the regulated combustion chamber temperature, as hereinafter explained.

As will appear hereinafter, the control 28 is designed for five phases of operation as follows:

1. Cut-off—when the engine is at rest and the fuel line has been closed by the equalizer valve 38 and throttling valve 41.

2. Starting operation—the system of control for which is shown by Figure 1.

3. Ground idle operation effective immediately after the starting cycle has been completed—the system of control for which is shown in Figure 3 with the several switches adjusted as shown in dotted lines by the designation (3).

4. Normal ground operation—the system of control for which is shown in Figure 3 with the several switches adjusted to the position shown in dotted lines by the designation (4).

5. Flight operation—the system of control for which is shown in Figure 3 with the several switches adjusted to the positions shown in solid lines by the designation (5).

System of control for starting operation—Figure 1

Referring to the drawing of Figure 1, there is shown diagrammatically a system of control for starting a turbine type engine in which the temperature responsive elements 32 and 30 are shown as thermocouples connected in a loop circuit including control windings 50 and 51 of magnetic amplifiers 52 and 53. The magnetic amplifiers 52 and 53 include serially connected excitation windings 54 and 55 connected across a main source of constant frequency alternating current. The magnetic amplifiers 52 and 53 also include D. C. bias windings 56 and 57 and the controlled windings 58 and 59 inductively coupled to the excitation windings 52 and 53 respectively. The thermocouples 30 and 32 are connected in opposing relation so that the control signal energizing the windings 50 and 51 will represent the difference between the temperatures at the compressor inlet and at the combustion chamber 12 which will in turn vary the induced voltage in the regulating windings 58 and 59 in direction relation to the difference between such temperatures.

The windings 58 and 59 are serially connected to one of the inputs of a mixer circuit indicated generally by the numeral 60. The mixer circuit 60 may be of a conventional type or may be of a type such as disclosed in the said copending application Serial No. 156,260.

The other input to the mixer circuit 60 is grounded during starting operation by a switch 61 closing grounded contact 62. The opposite end of the serially connected control winding 58 and 59 is connected through a switch 63 which during the starting operation closes a contact 64 and through a second switch 65 which during the starting operation closes a contact 66 so as to connect in series with the control windings 58 and 59 an output winding 67 of a rate generator, the purpose of which will be explained hereinafter.

The opposite end of the generator winding 67 is connected through a conductor 68 to a point on a potentiometer 69 which potentiometer is connected across a secondary winding 70 of the transformer 71. The transformer 71 has a primary winding 72 connected across the main source of constant frequency alternating current so as to induce in the secondary winding 70 a voltage acting in opposition to the voltage induced in the control windings 58 and 59. One end of the potentiometer 69 is connected by a conductor 73 to a point of the potentiometer 74 having one end grounded at 75 and the other end connected by a conductor 76 to a follow-up winding 77 grounded at 78. Inductively coupled to the follow-up winding 77 is a rotor winding 79 connected across the main source of alternating current and positioned through a shaft 81 by actuator motor 82 as will be explained hereinafter.

It will be seen then that upon the voltages induced in the winding 70 and control windings 58 and 59 being unbalanced a signal voltage will be applied through the mixer system 60 to output lines 83 of the mixer system to the input of a suitable amplifier 84. The amplifier 84 may be of a conventional type or may be of a type such as disclosed in U. S. Patent No. 2,493,605 granted January

3, 1950 to Adolph Warsher and assigned to Bendix Aviation Corporation.

The output of the amplifier 84 leads through output lines 85 to a limiter potentiometer 86 and thence to an input of an amplifier 87, likewise of conventional type. Output 88 from the amplifier 87 leads to the control winding 89 of a two phase actuator motor 82 having its fixed phase winding 90 connected across the main source of alternating current.

The actuator motor 82 is arranged to drive through the shaft 81, the throttling valve 41 (Figure 4) so as to increase or decrease the flow of fuel to the engine depending upon the direction of unbalance of the main control system including control windings 58, 59 and 70. In actuating the shaft 81 in an opening direction, for example, to increase the fuel supply to the engine in response to a call for increase in temperature, the shaft 81 will also adjustably position the followup rotor winding 79 so as to induce in the winding 77 a voltage tending to counteract the signal voltage calling for increase in fuel or temperature and thereby in effect decreasing the temperature setting with movement of the valve in an opening direction by the motor 82. Similarly, upon the temperature tending to exceed the selected ceiling temperature, the motor 82 will position the valve in a closing direction and the follow-up winding 79 in a direction tending to induce a voltage in the winding 77 counteracting the signal voltage calling for a closing movement of the throttling valve and tending to increase the temperature setting.

It is seen then that as speed of the turbine continues to increase at ceiling temperature drawing more air into the combustion chamber 12 and calling in turn for increase in fuel and temperature, the controlled variable temperature will decrease with increase in speed during this transient causing adjustment of the actuator motor 82 in a direction calling for more fuel while positioning the follow-up winding 79 so as to reset the selected temperature of the winding 79 to a lower value. This is desirable to prevent stall during fire-up.

Referring now to the drawing of Figure 1, the flyball governor 27 driven by the shaft 26 senses the speed of the turbine 25 and is arranged to adjustably position a rotor winding 100 connected across a main source of constant frequency alternating current. The winding 100 forms a rotor portion of a variable coupling transfer 102 having a stator winding 104 inductively coupled thereto. The stator winding 104 is operatively connected through suitable electrical conductors to a stator winding 195 of a second variable coupling transformer 197 having a rotor winding 109. Rotor winding 109 is connected through suitable conductors to the input of an amplifier 111 which may be a type well known in the art or of a type such as shown in the said U. S. Patent No. 2,493,605. The output of the amplifier 111 is connected through conductors 113 to a control winding 115 of a two phase reversible servomotor 117 having another winding 119 connected across the main source of alternating current. As indicated diagrammatically in Figure 1, the servomotor 117 drives through a shaft 121 suitable rotary switch elements 123, 125, 127, 129, 131 and 133 and also the rotary winding 109 so as to follow the position of the first winding 100. Thus adjustment of the rotor winding 100 in response to a change in speed as sensed by the governor 27 will cause through the servomotor 117 a like adjustment of the rotor winding 109 to a null position together with adjustment of the rotary switch elements 123—133.

Cooperating with the rotary switch elements 123—133 are respective brush elements 135, 137, 139, 141, 143 and 145 which cooperate with the relay switch system shown diagrammatically in Figure 2 as hereinafter explained.

Switching system

Referring now to Figure 2, in order to effect the auto-

matic starting operation, a cut-off switch indicated by the numeral 150 must be first closed so as to effect energization of a relay winding 151 of the relay mechanism 153 having movable contacts 155, 157 and 158. Such energization of the winding 151 will then cause contact 155 to close contact 155A while contact 157 closes contact 157A and contact 158 engages an open contact 158A. The closing of contact 155A by the movable contact 155 will then effect energization of a relay winding 160 through line 162. The closing of contact 157A by movable contact 157 will similarly cause energization of a relay winding 165 through a conductor 167.

The relay winding 160 controls movable contacts 170, 171 and 173 and upon energization of the relay 160 the movable contact 170 closes contact 170A, the movable contact 171 closes contact 171A and movable contact 173 engages open contact 173A.

The energization of the relay winding 165 similarly causes movable contacts 180, 181, 182, 183, 184, 185, 186, 187 and 188 to close cooperating contacts 180A, 181A, 182A, 183A, 184A, 185A, 186A, 187A and 188A. The closing of contact 180A by the movable contact 180 effects through the conductor 190 and 191 a holding circuit for the relay windings 160 and 165 through the rotary switches 125 and 129 heretofore explained.

Now, when it is desired to start the engine, the cut-off switch 150 is opened causing deenergization of the relay winding 151 whereupon the movable contacts 155, 157 and 158 are biased under suitable spring means not shown, so as to open the contacts 155A, 157A and 158A and close contacts 155B, 157B and 158B. The closing of contact 158B by the movable contact 158 then effects through a conductor 195 and rotary switch 131 and 133 energization of electromagnetic winding 197. The relay winding 197 controls a movable contact 220 which upon energization of the winding 197 closes contact 201 so as to complete a circuit for effecting energization of a suitable starting mechanism 36 to drive the turbine engine. Deenergization of the winding 151 also causes the movable contact 157 to open the contact 157A and thus break the circuit through the conductor 167 to the relay winding 165, which, however, continues to be energized through the rotary switch 129 and the holding contact 180A and 180. Likewise, deenergization of relay winding 151 causes the movable contact 155 to open the contact 155A so as to open the conductor 162 to relay winding 160. The relay winding 160, however, continues to be energized through the rotary switch 125 and the holding contacts 180 and 180A.

At a predetermined driven speed of the turbine as sensed by the flyball governor 27 of, say for example, 2000 R. P. M., the flyball governor 27 causes adjustment of the rotor winding 100 of the variable coupling transformer 102 and thereby rotation of the servomotor 117 in a direction such that the rotary switch 125 opens the energizing circuit for the winding 160 whereupon movable contact 170 opens contact 170A controlling the circuit for holding the flow equalizer valve heretofore described in a shut-off position so that fuel may now flow to the combustion chamber of the engine through the equalizer valve. Similarly the movable contact 171 opens contact 171A and closes contact 171B for permitting motor 82 to open the throttling valve 41 in response to a signal for increase in temperature.

In the cut-off position, the movable contact 171 closes a contact 171A in response to energization of relay winding 160. The contact 171A, as indicated in Figure 2, is connected to a conductor 200 which, as indicated in Figure 3, leads to a point 201 on a potentiometer 202 connected across a primary winding 203 of a transformer having a primary winding 204. The primary winding 204 connected across the main source of alternating current is arranged to induce into the winding 203 an alternating current of such a phase as to cause rotation of the actuator motor 82 in a direction to close the throt-

thling valve 41 to passage of fuel. The output of the secondary winding 203 is connected to input conductor 205 of an amplifier 206 while the other input line 205A of the amplifier 206 is grounded. The opposite output conductor 200 from the secondary winding 203 leads through contact 171A, movable contact switch 171 and conductor 207 to a switch 181 closing a grounded contact 181A. Corresponding switches are indicated in Figure 3 by dotted lines as connecting line 200 to line 207 and line 207 to ground. The latter ground connection is effected in Figure 2 by the movable switch contact 181 which closes contact 181A upon energization of the electromagnetic winding 165.

It will be seen then that the output of the secondary winding 203 of the transformer 204 is then connected to the input of the amplifier 206 through conductor 205 and grounded conductor 205A. The amplifier 206 may be of a conventional type or may be of a type such as disclosed in the said U. S. Patent No. 2,493,605. The output 207 of the amplifier 206 is connected through a phase selector 208 having an output 208A leading to the input of the amplifier 87. The phase selector may be of a conventional type or a type such as disclosed in the pending application Serial No. 41,329, filed July 29, 1948 by William E. Brandau and is arranged to permit a signal voltage of a phase corresponding to that induced through the secondary winding 203 to the phase selector 208 to pass, while not permitting the passage, of a signal voltage of an opposite phase. The signal voltage which phase selector 208 permits to pass is of such a phase as to cause the motor 82 to drive the throttling valve 41 in a direction for closing the valve 41 to cut off the passage of fuel to the combustion chamber 12.

Now, upon the cut-off switch 150 being opened and the electromagnetic winding 160 being deenergized, as upon the turbine 20 being driven by the starter 36 to a speed sufficient to open the rotary switch 125, such as, for example, 2000 R. P. M., then the movable switch contact 171 opens contact 171A and closes contact 171B. The contact 171B, as indicated in Figure 2, is connected to a conductor 209 which, as indicated in Fig. 3, leads to a point 210 on a potentiometer 211 connected across a secondary winding 213 inductively coupled to the primary winding 204 and so arranged that there is induced into the secondary winding 213 a voltage having an opposite phase relation to that induced in the secondary winding 203. The output of the secondary winding 213 is connected to the input conductor 205 of the amplifier 206 while the other input line 205A of the amplifier 206 is connected to a common ground connection to which the opposite output conductor 209 is connected through contact 171B, movable contact switch 171, conductor 207 and switch 181 closing ground contact 181A. Corresponding switches are indicated in Figure 3 by dotted lines as connecting line 209 to line 207 and line 207 to the common ground. Thus, the output of the secondary winding 213 is connected to the input of the amplifier 206. However, the phase selector 208 is so arranged that signal voltages of a phase opposite to that induced in the winding 203 are not permitted to pass through the phase selector 208. Therefore, the signal voltages from the winding 213 do not pass to the amplifier 87 from the phase selector 208 and the servomotor 44 may adjust the throttling valve 41 in an opening direction as determined by the temperature responsive control heretofore described.

Deenergization of the electromagnet 160 also causes movable contact 173 to close 173B for effecting through rotary switch 131 energization of a relay winding 215. The energization of relay winding 215 causes a movable contact 216 to close a contact 217 for effecting operation of the ignitor 35 for igniting gases in the combustion chamber 12 for starting the engine.

A fuel flowing to the combustion chamber 12 through the throttling valve 41 and the equalizer valve 38 now

starts to burn and the temperature in the combustion chamber rises until the ceiling temperature set by the connection of the conductor 68 to the potentiometer 69 of Figure 1 is achieved.

It will be noted that, as shown in Figures 2 and 3, the movable contact 65 closes contact 66 upon energization of the winding 165, causing in turn the energization of the relay winding 220; energization of relay winding 220 in turn causes a movable contact 65 to close a movable contact 66 connecting into the temperature loop the output winding 67 of a rate generator 226. The rate generator 226 has a winding 227 connected across a main source of alternating current and has a rotor driven through shaft 228 by the servomotor 117 at a speed proportional to the acceleration of the turbine 20.

The output of the rate generator 226 has a frequency determined by the main source connected across winding 227 and the output voltage is proportional to engine acceleration and is connected in the temperature sensitive circuit by the contacts 65-66. The rate generator 226 is arranged to introduce a feed back voltage having a phase relation such as to reduce the selected temperature level with increase in engine acceleration. Since the characteristic of turbine engines is relatively poor efficiency at low speeds, a fixed operating temperature sufficiently high to guarantee acceleration of the engine at starting speed results in a runaway acceleration as the rated speed is approached. The acceleration feed back introduced by the rate generator 226 acts to moderate this tendency.

Speed continues to increase however, at ceiling temperature and it will be noted that the control temperature setting decreases with increase in speed during this transient since the position follow-up 79 tends to reset the selected temperature to a lower value.

This is desirable to prevent stall during fire-up.

When the turbine reaches a predetermined self-sustained speed of, for example, 4000 R. P. M. the rotary switch 133 opens to deenergize electromagnet 197 whereupon the movable contact 200 opens the contact 201 and deenergizes the starter mechanism while the rotary switch 131 opens to deenergize the relay winding 215 whereupon the movable contact 216 opens the contact 217 to deenergize and extinguish the ignitor mechanism 35.

Further, when the speed of the turbine reaches an additional self-sustained speed of, for example, 5500 R. P. M., the rotary switch 129 opens the energizing circuit for the relay winding 165 whereupon the several movable contacts 180-188 open respective contacts 180A to 188A while closing the associate contacts 181B, 183B, 184B and 187B so as to transfer the circuit shown in Figure 1 to the circuit shown in Figure 3 for normal ground operation.

More precisely, a holding circuit for the relay windings 160, 165, 197 and 215 controlled by the speed sensitive switches 125, 129, 131 and 133 is broken by the opening of contacts 180 and 180A upon deenergization of winding 165 and the starting cycle cannot be re-initiated without first closing the cut-off switch 150. This arrangement thus prevents accidental re-energization of the starter and ignitor equipment in the event the engine should stall.

Furthermore, the deenergization of the electromagnetic winding 165 permits the movable contacts 181, 182, 183, 184, 185, 186, 187 and 188 under suitable spring means to open contacts 181A-188A respectively and close associated contacts 182-187B respectively so as to transfer the connection of the speed variable coupling transformer and speed follower variable coupling transformer 107 of Figure 1 from the system shown in Figure 1 to that shown in Figure 3 for normal operation.

Thus, deenergization of the electromagnetic winding 165 causes the movable contact 181 to open the contact 181A so as to open the ground connection of line 207 and the movable contact 187 to open contact 187A and close contact 187B to connect line 200 to line 207 as indicated schematically by dotted lines in Figure 3.

Further, upon such deenergization of the winding 165,

the movable contact 182 opens contact 182A and connects the line 76 from the follow-up winding 77 to the stator winding 105 of the variable coupling transformer 107, as indicated schematically in Figure 3, while movable switch contact 183 opens contact 183A to disconnect the rotor winding 109 of the variable coupling transformer 107 from the input of the amplifier 111 and close contact 183B to connect the rotor winding 109 across the main source of alternating current. Thus, upon deenergization of the winding 65, the connection of rotor winding 109 is transferred from that shown in Figure 1 to that shown in Figure 3.

Moreover, movable contact 184 upon deenergization of the relay winding 165 closes contact 184B to connect the output winding 67 of the rate generator 226 in the input line to the amplifier 111, as indicated schematically in Figure 3. Further, the switches 181, 182 and 185 are arranged, as shown in Figures 1 and 2, to transfer the connections of the variable coupling transformers 102 and 107 from that shown in Figure 1 to that shown schematically in Figure 3 upon deenergization of the winding 165.

Furthermore, the movable contact 186 opens the contact 186A so as to potentially deenergize the electromagnet 220 in the event the pilot should transfer control from ground idle operation to normal ground operation by opening the switch 225. In the closed position of the switch 225, the system remains in ground idle operation and the electromagnetic winding 220 continues energizing.

The movable contact 187 upon deenergization of the relay winding 165 further opens contact 187A and closes the contact 187B so as to in effect cause the switch of Figure 3 indicated in dotted lines to close the contact for a maximum speed limit of, for example, 6000 R. P. M., which serves to override the existing temperature setting as will be explained.

Normal ground operation

To effect normal ground operation, the pilot may now move a selector switch 225 to an open position de-energizing electromagnetic winding 220 causing a movable contact 230 to open associated contact 230A and close associated contact 230B so as to in effect shift the speed selector switch 230 of Figure 3 as indicated in dotted lines to the contact 230B which raises that speed ceiling to a higher value of, for example, 7088 R. P. M.

Furthermore, the de-energization of electromagnet 220 causes a movable contact 232 to open associated contact 232A and close associated contact 232B which effects a circuit for controlling the propeller pitch by a suitable mechanism which may be of conventional design and which forms no part of the present invention. The de-energization of the electromagnet 220 causes movable contact 65 to open a contact 66, shown in Figure 1 and heretofore described, and close a second contact 66A, as shown in Figure 3, which increases the temperature ceiling of the regulating system from that of the setting of Figure 1 to that of setting of Figure 3.

The de-energization of the electromagnet 220 also causes movable contact 235 to open an associated contact 235A which potentially de-energizes a second electromagnet 240 in the event the pilot should open a switch 242 to transfer from normal ground operation to flight operation.

During ground operation with the switch 242 closed, it is expected to maneuver the airplane by maintaining the preset speed of, for example, 7088 R. P. M. of the over-speed governor and varying power by adjusting the blade angle of the propeller to give forward and reverse thrust at the same time. The speed is isochronous (dead beat, no droop) as the follower 77 is wiped out by the speed control circuit.

Flight operation

For flight operation the pilot may open switch 242

to de-energize the relay 240 whereupon movable contacts 245, 247, 63, 251 and 253 are biased by suitable spring means to open associated contacts 245A, 247A, 64, 251A and 253A, respectively, and close associated contacts 245B, 247B, 64A, 251B and 253B. The opening of contact 245A and the closing of contact 245B in effect shifts the speed selector switch 245 of Figure 3 to close a contact 245B as indicated by solid line in Figure 3 which increases the speed level from the previously selected value of, for example 7088 R. P. M. to a higher level of, for example, 7200 R. P. M.

Moreover, the opening of contact 247A and the closing of the contact 247B puts the propeller pitch governor in normal speed control by a mechanism of conventional design which forms no part of the present application.

Further, the opening of contact 64 and the closing of contact 64A in effect causes a like designated switch 63 in Figure 3 to close a contact 64A to change the temperature of a control system from a fixed ceiling to one which is variable by movement of the pilot's power control lever 46 as indicated in Figures 3 and 4.

The de-energization of the electromagnet 240 causes a movable contact 251 to open contact 251A and close contact 251B to cause a like indicated switch 251 in the system of Figure 3 to close a contact for transferring the reset variable coupling transformer from the arrangement of ground operation to that of flight operation indicated in Figure 3.

Furthermore, the de-energization of electromagnet 240 closes a movable contact 253 to open contact 253A and closes contact 253B to in effect cause a like indicated switch 253 in the system of Figure 3 to connect into the mixer system 69 signals for operation of the regulator system during normal flight operation.

Operation of overspeed control

During ground idle operation the secondary winding 203 provides a signal voltage of a phase which is opposed by the signal voltage of the variable coupling transformer 102 which is of opposite phase and, therefore, so long as the signal voltage across the output lines 200—205 of the primary winding 203 does not exceed the signal voltage of the variable coupling transformer 102 no signal passes through the phase selector 208. However, as the speed of the turbine 20 increases the rotor winding 100 is adjusted so as to decrease the voltage induced in the stator winding 104 until at the predetermined maximum speed of, for example, 6000 R. P. M. the signal voltage at the output lines 200—205 exceeds that of the signal voltage from the variable coupling transformer 102 so that thereupon a signal voltage passes through the phase selector 208. Such signal voltage passed by the phase selector 208 affects the amplifier 87 and actuator motor 82 so as to adjust the throttling valve 41 to decrease the fuel supply to decrease the engine temperature and speed so that during normal ground idle operation the engine operates at a steady predetermined speed of, for example, 6000 R. P. M.

Now upon the switch 230 being adjusted to close contact 230B for connecting line 207 to line 209 as during normal ground operation a signal voltage is supplied by output lines 205—209 of the secondary winding 213 instead of the secondary winding 203. The signal voltage supplied by the secondary winding 213 will be in phase with that supplied by the variable coupling transformer 102 at the first predetermined speed of, for example, 6000 R. P. M., but as the speed of the turbine 20 increases adjustment of the rotor winding 100 by the fly-ball governor 27 causes an inversion in the signal voltage induced in the stator winding 104 of the variable coupling transformer 102 until as a predetermined speed of, for example, 7088 R. P. M. is approached, the signal voltage induced in the stator winding 104 of opposite phase tends to balance that induced in the secondary winding 213 and upon this predetermined speed being

exceeded the signal voltage induced in the winding 104 exceeds that in the secondary winding 213 and passes the phase selector 208 so as to cause actuator motor 82 to move in a direction to decrease the fuel supply to the combustion chamber 12 to decrease the engine temperature and speed so that during normal ground operation the engine operates at a steady predetermined speed of, for example, 7088 R. P. M.

Now upon the switch 245 being adjusted so as to open contact 245A and close contact 245B so as to transfer from output line 209 to output line 209A a higher predetermined speed is selected of, for example, 7200 R. P. M. and upon the rotor winding 100 being further adjusted by the fly-ball governor in a speed increasing direction the voltage induced in stator winding 104 exceeds that across the output lines 205 and 209A to limit the speed of the turbine at the predetermined speed of 7200 R. P. M.

It will be seen from the foregoing that the speed sensing unit of Figure 1 is the same fly-ball governor 27 and variable coupling transformer 102 which is used during normal operation to supply speed sense to the electronic control system in terms of a voltage signal. For the start cycle, however, this speed transformer 102 is coupled to the reset transformer 107 which acts as servo operated follower of speed as shown in Figure 1. The reset transformer 107 during normal ground idle and ground operation is coupled in series with the follow-up transformer 77 to affect the reset amplifier and thereby the reset actuator motor so as to cause adjustment of rotor winding 109 in a direction to cancel out the follow-up voltage induced in winding 77 by adjustment of the rotor winding 79 by the valve actuator motor 82 and thereby remove the follow-up temperature drooping effect. In the starting operation such follow-up temperature drooping effect is not removed and as heretofore explained it is a desirable characteristic in the starting operation to have such temperature droop with increasing speed.

In the start cycle a position follower is required and not a voltage follower and to achieve this the stator windings 104 and 105 (speed and reset) are interconnected as shown in Figure 1. The rotor 100 of the speed transformer has an excitation voltage applied, while the rotor of the reset transformer 105 is connected during the starting operation to the input of the reset amplifier 111 as shown in Figure 1. In this way the reset actuator motor 117 acts to crank the reset rotor 109 through shaft 121 to a null position which corresponds to the transformer 109 rotor position and the result is a servo operated speed follower to open and close suitable switches for effecting the several functions in the starting operation heretofore described.

The selected temperature for the start cycle (the controlling factor) is low enough to prevent compressor stall, and at the same time high enough to provide an accelerating torque in the engine throughout the start cycle. The actual control circuit itself is a modified version of that used in normal operation. The "effective follow-up" signal used in the ground idle and ground operation circuit, is not available during a start, since the reset transformer 105 has been taken out of the circuit. A direct follow-up signal is supplied to the circuit in its stead by the adjustment of the rotor winding 79 relative to the winding 77 by the actuator motor 82, as shown in Figure 1. Using a direct follow-up in this manner introduces temperature droop. The maximum variation in temperature directly due to this droop does not exceed 25 degrees Fahrenheit.

The engine after starting will continue to accelerate up to the ground idle R. P. M. At approximately 500 R. P. M. below ground idle the transfer relay controlled by rotary switch 129 switches over to normal operation, ground idle. The starter 36 and ignitor 35 are both arranged to be cut out by suitable rotary switch relay operated means at some point below the transfer R. P. M.

The key to a smooth transfer of control functions at this point is the relative position of the reset transformer 107. The position of the reset transformer 107 as a speed follower should closely approximate the position of the reset in the follow-up loop for average ground idle operation.

Having completed the start, all relays used in the start cycle are de-energized and in addition the voltage supply to the start rotary switch is cut off. Repetition of the start cycle, or any portion of it may only be initiated by going through the cut-off position.

Flight operation

When the switching mechanism has been adjusted to the position for effecting normal flight operation, as indicated in Figure 3, it will be seen that the ceiling temperature selector 63 for ground operation is cut out of the temperature circuit by the switch 63 and in its stead there is operably connected a transformer 300 having stator windings 302 and rotor winding 303 connected across the main source of alternating current. The rotor winding 303 may be variably positioned through operation of the lever 46 to select the desired temperature.

Further connected in series with the stator windings 302 of the transformer 300 is an output winding 305 of a rate generator 307 having a winding 309 energized from the main source of alternating current and a rotor 310 driven by the actuator motor 82 so as to apply to the temperature responsive loop a follow-up signal voltage proportional to speed of change in position of the throttling valve 41 and tending to retard rapid change of position of the throttling valve 41 so as to maintain stability of control.

The output voltage of the rate generator 307 is also applied across the cathode and grid of an electronic valve 310 so as to cause a cathode plate voltage in the primary winding 312 to produce in the secondary winding 314 of the transformer 316 a follow-up signal voltage. Such follow-up is in turn applied in the overspeed loop so as to tend to retard rapid change in the position of the throttling valve 41 under overspeed conditions and thereby provide stability of control in the overspeed governor.

Furthermore, the adjustment of the switch 253 to open grounded contact 253A and close contact 253B to the mixer system 60 permits the follow-up transformer 77-79 to apply a follow-up signal to the temperature loop which is in turn wiped out by the action of reset transformer 107 having the rotor winding driven by the reset motor 117. It will be also noted that the rate generator 226 applies through the output winding 67 a rate signal to the input of the reset amplifier 111 proportional to the driven speed of the rotor 109 so as to retard rapid change of position of the reset winding 109 and thereby provide stability of control.

Although only one embodiment of the invention has been described and illustrated in detail, it is to be expressly understood that the same is not limited thereto. Various changes may be made in design and arrangement of the parts illustrated, as will be apparent to those skilled in the art. For a definition of the limits of the invention, reference should be had to the appended claims.

What is claimed is:

1. A control system for starting an engine; comprising, in combination, an engine speed sensing device, a first variable coupling transformer having a pair of inductively coupled windings, one of said windings being operatively positioned relative to the other winding by said speed sensing device, a second variable coupling transformer having a pair of inductively coupled windings, one of the windings of said first transformer operatively connected to one of the windings of said second transformer, a reversible servomotor drivingly connected to position one of the windings of said second transformer relative to the other winding of said second transformer, said servomotor controlled by the voltage induced in one winding of said second transformer by the other winding to position

13

one of the windings relative to the other winding of said second transformer to a position corresponding to the relative position of the windings of said first transformer, and a switching mechanism controlled by said servomotor to open and close circuits controlling the starting operation of the engine as the sensed speed of the engine changes.

2. The combination defined by claim 1 in which the switching mechanism includes a first switching means for initiating operation of a starting motor for driving the engine, second switching means controlled by the servomotor for initiating operation of a fuel supply means for the engine and operation of an ignitor device for the engine fuel at a first predetermined engine driven speed, and third switching means controlled by the servomotor for terminating operation of the starting motor and ignitor device at a greater predetermined self-sustained speed of the engine.

3. The combination defined by claim 2 including engine temperature responsive means for regulating the fuel supply to maintain an engine ceiling temperature, and means driven by the servo-motor for retarding the rate of acceleration of said engine at said ceiling temperature.

4. The combination defined by claim 3 including a fourth switching means controlled by the servo-motor for increasing the engine ceiling temperature.

5. For use in starting an aircraft engine having a fuel intake conduit for said engine and means for controlling the supply of fuel through said conduit to said engine; the combination comprising engine temperature responsive means for regulating said control means to maintain a predetermined engine ceiling temperature, means responsive to engine speed for retarding the rate of acceleration of said engine at ceiling temperature, said last mentioned means including a device sensitive to engine speed, a servomotor controlled by said device, a rate generator driven by said servo motor and having a voltage output proportional to the rate of acceleration of said engine, and said rate generator operatively connected to the temperature responsive means in such a manner as to tend to decrease the temperature ceiling so as to retard acceleration of said engine at ceiling temperature.

6. For use with an aircraft engine having a combustion chamber, an air intake conduit to said chamber, a fuel intake conduit to said chamber, a turbine driven by the combustion gases from said chamber, a compressor driven by said turbine to supply air to the intake conduit, and means to control the supply of fuel to said combustion chamber; an automatic starter control comprising, in combination, combustion gas temperature responsive means to regulate the fuel supply control so as to maintain the combustion gases at a predetermined temperature during starting operation, a turbine speed responsive means, a servomotor controlled by the last mentioned means, switching means operated by said servomotor to control the starting operation as the speed of the turbine increases, and means driven by said servomotor to decrease the predetermined temperature with increase in turbine acceleration to retard the acceleration of said turbine.

7. For use with an aircraft engine having a combustion chamber, an air intake conduit to said chamber, a fuel intake conduit to said chamber, a turbine driven by the combustion gases from said chamber, a compressor driven by said turbine to supply air to the intake conduit, and means to control the supply of fuel to said combustion chamber; an automatic starter control comprising, in combination, combustion gas temperature responsive means to regulate the fuel supply control so as to maintain the combustion gases at a predetermined temperature during starting operation, a turbine speed responsive means, a servomotor controlled by the speed responsive means, a generator driven by said servomotor and operatively connected to the fuel regulating means so as to retard acceleration of the turbine, and switching means operated by said motor to affect the

14

starting operation of said engine as the speed of the turbine increases.

8. For use with an aircraft engine having a combustion chamber, an air intake conduit to said chamber, a fuel intake conduit to said chamber, a turbine driven by the combustion gases from said chamber, a compressor driven by said turbine to supply air to the intake conduit, and means to control the supply of fuel to said combustion chamber; an automatic starter control comprising, in combination, combustion gas temperature responsive means to regulate the fuel supply control so as to maintain the combustion gases at a predetermined temperature during the starting operation, a servomotor to operate said fuel supply control, a generator driven by said servomotor and having a voltage output proportional to the speed of said motor, means operatively connecting the output of said generator to said regulating means to vary said predetermined combustion gas temperature so as to retard acceleration of said turbine.

9. For use with an aircraft engine having a combustion chamber, an air intake conduit to said chamber, a fuel intake conduit to said chamber, a turbine driven by the combustion gases from said chamber, a compressor driven by said turbine to supply air to the intake conduit, and means to control the supply of fuel to said combustion chamber; the combination comprising temperature responsive means for operating said fuel control means so as to maintain a selected combustion chamber temperature, turbine speed responsive means, a servomotor means for controlling starting operation of said turbine, means operatively connecting said turbine speed responsive means to said servomotor means, and means to transfer said operative connection from said servomotor means to said fuel control means.

10. The combination defined by claim 9 including switch means operated by said servomotor means at a predetermined turbine speed to transfer said operative connection from said servomotor means to said fuel control means so that the speed responsive means may operate said fuel control means to prevent the turbine speed from exceeding a predetermined value.

11. A starter control for an aircraft engine, comprising, in combination, inductive coupling means, means responsive to engine speed operatively connected to said inductive coupling means, means to control the starting operation of the engine, fuel control means for the engine, and means to selectively connect said engine speed responsive means through the inductive coupling means to the starting control means during starting operation and through the inductive coupling means to said fuel control means upon completion of the starting operation.

12. A starter control for an aircraft engine, comprising, in combination, inductive coupling means responsive to engine speed, means to control the starting operation of the engine, fuel control means for the engine, switching means to operatively connect said inductive coupling means to the starting control means during starting operation and to said fuel control means upon completion of the starting operation, and said switching means being controlled by said starting control means.

13. The combination comprising, engine speed responsive means, engine starting control means, engine fuel control means, variable inductive coupling means controlled by said engine speed responsive means, and means operated by said engine speed responsive means to selectively connect said speed responsive means through said inductive coupling means to said starting control means during starting operation and to said fuel control means upon completion of the starting operation.

14. The combination comprising engine speed responsive means, engine starting control means, inductive coupling means for operatively connecting said speed responsive means to said engine starting control means, engine fuel control means, means to operate said fuel

15

control means to prevent flow of fuel to the engine, means operated by said engine starting control means to terminate operation of the fuel flow preventing means, and other means operated by said engine starting control means to reinitiate operation of the fuel flow preventing means and operatively connect the engine speed responsive means through said inductive coupling means to said engine fuel control means to oppose the operation of said engine fuel flow preventing means at all speeds less than a predetermined value and permitting said engine fuel flow preventing means to operate said fuel control means so as to limit the flow of fuel at speeds in excess of said predetermined value.

15. A control system for starting an engine, comprising, in combination, an engine speed sensing device, a reversible servomotor controlled by said speed sensing device, a switching mechanism driven by said servomotor to open and close circuits controlling the starting operation of the engine as the sensed speed of the engine changes, said switching mechanism including a first switching means for initiating operation of a starting motor for driving the engine, second switching means controlled by the servomotor for initiating operation of a fuel supply means for the engine and operation of an ignitor device for the engine fuel at a first predetermined engine driven speed, and third switching means controlled by the servomotor for terminating operation of the starting motor and ignitor device at a greater predetermined self-sustained speed of the engine.

16. A control system for starting an engine, comprising, in combination, an engine speed sensing device, a reversible servomotor controlled by said speed sensing device, a switching mechanism driven by said servomotor to open and close circuits controlling the starting operation of the engine as the sensed speed of the engine

16

changes, engine temperature responsive means for regulating the fuel supply to maintain an engine ceiling temperature, and means driven by the servomotor for retarding the rate of acceleration of said engine at said ceiling temperature.

17. A control system for starting an engine, comprising, in combination, an engine speed sensing device, a reversible servomotor controlled by said speed sensing device, a switching mechanism driven by said servomotor to open and close circuits controlling the starting operation of the engine as the sensed speed of the engine changes, said switching mechanism including switching means controlled by the servomotor for increasing the engine ceiling temperature.

18. The combination comprising engine speed responsive means, engine starting control means, engine fuel control means, means operatively connecting said speed responsive means to said engine starting control means, transfer means for disconnecting said starting control means from the speed responsive means and connecting said engine fuel control means thereto, and means operatively connecting the speed responsive means to said transfer means.

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