SYSTEM FOR ACCELERATING ENGINES TO SELECTED SPEEDS AND MAINTAINING THE SPEED SELECTED

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[Diagram of the system with labels and connections]

Fig. 1.

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SYSTEM FOR ACCELERATING ENGINES TO SELECTED SPEEDS AND MAINTAINING THE SPEED SELECTED

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This invention relates to control systems for engines as disclosed in my copending application Serial No. 770,872, filed August 27, 1947, now Patent No. 2,662,372, and in particular to an improved arrangement for controlling acceleration of an engine from an idling to a selected running speed in a manner consistent with maximum engine efficiency of engines of the turbojet type. The present control system is especially applicable to engines of the turbojet type where the engine is controlled by the combination gas turbine type widely known as a turbojet and it is with respect to such application that the invention is herein illustrated and described. It will be understood that some aspects of the various principles involved are applicable as well to other types of engines and the appended claims are to be construed accordingly.

Another object of the invention is to provide a substantially all-electronic speed and acceleration control for turbojet engines that is extremely simple and reliable in operation, is relatively insensitive to large changes in ambient temperature or pressure and which will maintain the desired speed and acceleration within very close limits.

Engine tests have shown that any selected engine speed is held automatically within one half per cent. Only one throttle or control lever is required and engine response to its movements is rapid but automatically held within the limits of safe engine operation.

Another object of the invention is to provide an adjustable speed control for turbo-jet engines in which the fuel supply to the engine for acceleration purposes is directly responsive to the need of the engine, temperature and any selected speed thereafter maintained as a function of instantaneous engine speed as compared with the selected speed.

Another object is to provide a speed control for turbojet engines which permits the engine to be accelerated for any speed at a temperature close to but not exceeding a predetermined maximum allowable temperature in the tail pipe. With present turbojet engines, this maximum temperature limit is about 1,500° F. While it is not permissible to exceed the temperature limit neither is it desirable to accelerate at a lower temperature since this makes the engine acceleration time factor undesirably long. The latter factor is extremely important in military aircraft since a quickly responsive governor is mandatory under certain flight maneuvers such as a carrier wave-off. Assuming a plane coming in for a landing on the carrier deck with fully retarded throttle, in the opinion of the landing officer flying at an altitude or speed unsafe for landing and the wave-off signal is given, it is essential that full engine power be available with the least possible time delay in the speed control system. The present system is admirably suited to such an eventuality and tests have shown that if the throttle lever is suddenly advanced after having been fully retarded for the engine is decelerating at its maximum rate, the fuel flow will increase to the maximum allowable value within one-half second after the throttle advance.

Another object is to provide a speed control for turbojet engines propelled by aircraft that will hold the engine speed constant with altitude and varying load without “drooping” or change of engine speed between a change in load or fuel flow and off-speed. Another object is to provide an adjustable electric speed control of the null-seeking type for aircraft turbojet engines featuring derivative damping wherein future values of both speed and engine temperature are electronically determined by the preceding rates of change of these functions, and in which the amount of the damping is varied automatically with changes in altitude and/or speed of the aircraft.

Another object is to provide a speed control system for turbo-jet engines in which acceleration is in some respects controlled as a function of engine temperature, the temperature schedule of the control being automatically adjusted as a function of engine speed and/or air temperature at the compressor inlet to prevent stalling of the compressor blading which in turn leads to undesirable surging in the compressor.

Yet another object is to provide a speed control for turbo-jet engines in which acceleration of the engine is controlled as a function of the temperature rise through at least one stage of the compressor in order to prevent compressor surge.

Still another object is to provide a speed control for turbo-jet engines in which the temperature rise through the compressor or at least a portion thereof is limited so that it will not exceed a value that is allowed to increase as the square of the engine speed.

Another object is to provide a speed control of the null seeking type for rotating elements wherein acceleration and speed of the member are controlled as a function of different parameters through a cross-over circuit that automatically selects the respective parameter signals, the cross-over circuit being comprised of cascaded unidirectional conducting devices in order to more effectively block out the non-selected signal from the control.

The foregoing as well as other objects and advantages of the invention will become more apparent from the following detailed description and accompanying drawings for a preferred embodiment in which:

Fig. 1 is a circuit diagram in block schematic of the improved electronic speed control;

Fig. 2 is a more detailed diagram showing circuit details of the principal components in Fig. 1;

Fig. 3 is a series of curves pertaining to a detail of the control;

Fig. 4 is a sub-circuit diagram illustrating a modified form of cross-over circuit components featuring cascaded rectifiers to improve their blocking action relative to incoming signals;

Fig. 5 is also a sub-circuit diagram showing a modified arrangement for the Fig. 2 control wherein acceleration of the engine is scheduled as a function of temperature rise across a stage of the compressor and the rate of change of engine speed to prevent the compressor from stalling;

Fig. 6 is likewise a sub-circuit diagram illustrating an alternative use of the circuit shown in Fig. 5 only for protection against compression surge in the engine leaving the main control functions on a basis of tail pipe temperature as shown in Fig. 2;

Fig. 7 is also a sub-circuit diagram illustrating a modification for a portion of the Fig. 2 circuit and which features scheduling of the derivative damping component of the speed signal in accordance with fuel flow; and

Fig. 8 depicts plots of engine temperature and speed respectively against time illustrating a typical engine response.

Referring now to the drawings and particularly Figs. 1 and 2 for the present, the fueling engine 9 is of typical design being comprised of a multi-stage axial flow compressor 9a driven by a single stage axial flow turbine 9b with a series of combustion chambers 9c; there being, and a tail pipe 9d through which the turbine exhaust gases are discharged rearwardly to effect forward propulsion of the engine.

Engine speed is sensed by a special tachometer generator QMN driven off the engine shaft 9e which puts out a direct current voltage proportional to speed. This voltage is compared with a reference voltage set by the throttle T in a bridge. The difference voltage and a derivative term derived from the generator output are combined to constitute the speed signal. Similarly, a temperature sensing element (in the present case a par-
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allel connected thermocouple group 3 in the tail pipe of the engine) is used to develop a voltage variable with tail pipe temperature, and this voltage combines with its corresponding temperature to form the resistance signal. The speed and temperature signals are both fed into an electronic selector which blocks one or the other of them depending upon the engine condition. At engine start-up, for example, the speed signal is passed at speeds higher than this only the speed signal is passed. The signal passed by the selector is then amplified and applied to a proportional solenoid 22 that controls the fuel valve 25 on the engine through a hydraulic servo 23, 24.

Speed circuit

The speed signal which exercises control over the speed of the engine after the cross-over point has been reached is obtained from a bridge circuit which includes the output from the tachometer direct current generator GEN driven by the engine, a speed selector potentiometer R102 adjusted by throttle T, and resistors R1 and R2. A large voltage is desired for the cross-over network in the selector circuit that is later described while a much smaller reference voltage is desired for the speed signals. Consequently, in the latter, the output of the potentiometer is divided by resistors R7, R8 to give the desired lower reference voltage for the speed circuit and the output is taken from the juncture of the point of R1 and R2. The tachometer generator is so designed that the armature voltage is very closely proportional to speed and field current. The generator field winding is connected in series with the speed selector potentiometer R102 to the positive terminal of a 28 v. source of direct current. Thus, if it be assumed that the speed signal is such that the bridge circuit is balanced and the bridge output therefore zero, then any fluctuation in the 28 v. supply will change the current through the generator field winding f and also through the speed setting potentiometer R102. But this change in field current will produce an exactly proportional change in the output voltage of the generator and hence the bridge will remain balanced.

It will be evident that for the same reasons, any variation in the resistance value of field winding f, or temperature will not affect the speed setting. Furthermore, the generator armature resistance will also be ineffective in causing speed changes.

As previously explained, the bridge functions to continuously compare the tachometer generator voltage with the speed reference voltage set by potentiometer R102 and puts out a speed signal component proportional to the difference between the two voltages and the potential of which (positive or negative) depends upon the direction of the bridge unbalance. In the present arrangement, if the generator voltage is below that set out by potentiometer R102, the speed signal component will be positive; if above, then the signal will have a negative polarity.

To improve the sensitivity-response characteristic of the control system, I prefer to combine with the speed signal component described in the preceding paragraph a derivative term which algebraically adds to such component another signal component that varies with the rate-of-change of the tachometer voltage. This is often referred to as derivative anticipation and makes it possible to stabilize the control system without the use of "droop." A satisfactory approximation of the speed derivative term is obtained through resistor-condenser circuit combinations. Since the amount of derivative term required for critical damping is a function of both attitude and speed, I prefer to vary the same automatically as the aircraft engine changes speed and/or altitude, by means of a control circuit R103 connected to the tacho meter T controlling the position of the speed selector potentiometer R102 which alters the capacitance of the condenser component as a function of speed and a variable resistor R103 controlled by an atmospheric pressure responsive bellows B for altering the resistance component as a function of altitude.

At sea level, the position of the bellows B will be such that the resistor has a minimum in-circuit value and the derivative term is established by a circuit to which the tachometer generator voltage is applied, the circuit including condenser C2 and resistor R3 connected in series and altitude variable resistor R60 shunting the same, the effect of the resistor R60 being to reduce the effect of the capacitor R23 on the signal and the derivative voltage that would be produced by the same. As the voltage setting on speed reference potentiometer R102 is changed, the effect of this speed, additional differentiating condensers C101, C102 are successively added in circuit with condenser C2 thus lengthening the time constant and increasing the derivative term. The speeds at which condensers C101, C102 come in, as well as their capacitance value are so chosen that satisfactory damping is obtained at all speeds.

As the altitude is increased from sea level, the attitude responsive bellows B progressively increases the in-circuit value of the shunting resistor R60. This further increases the derivative term and lengthens the differentiation time constant so that satisfactory damping will be maintained at all altitudes. These step like changes in the differentiation time constant as distinguished from a uniformly variable type of control has been found satisfactory since the amount of damping required is not too critical. Thus the time constant variable R60 values as speed is changed and variable shunting resistance with changes in altitude gives a derivative damping term which is the product of the two factors, and correct damping will be maintained over the full speed range as the altitude varies.

Any minor and slow fluctuations in the potential applied to the reference +28 volt terminal and which is usually obtained from battery voltage causes a negligible effect upon operation of the control system. However, in the event that the battery voltage should shift rapidly, the response of the speed generator circuit remains different from the response of the reference voltage source. This is so because the reference voltage is applied purely through resistive paths while the speed generator voltage is applied both through a resistive and a damping condenser C2. Thus the circuit while balanced for slow changes in the battery voltage, is not balanced for rapid changes. This drawback of variable condenser C60 connected between the output lead from the speed selector potentiometer R102 and one side of condenser C2, and which serves to make the time constant of both paths identical.

Condenser C60 also has another function. When small changes are made on the speed adjusting potentiometer R102, the normal action of the damping circuit without condenser C60 would be to delay the speed response of the engine according to the time constant of the damping circuit. Addition of condenser C60, however, cancels out the time constant of the damping circuit by the compensating time constant of the speed control circuit. Then, for small changes in potentiometer R102, very rapid response of the control system is made possible since large changes in potentiometer R102, the main amplifier for the signals saturates, and therefore the additional condenser C60 has little effect. This prevents the circuit from giving sudden excessively large increments of fuel which might result in over-temperature occurring so suddenly that the protective temperature over ride circuit, to be explained later, could not prevent damage to the engine.

To eliminate the derivative compensating effect it is best to vary the capacitance of condenser C60 with changes in the setting of potentiometer R102. When this capacitor is allowed a minimum in-circuit value this will maintain transient balance and this can easily be done by switching in successive values of this condenser with the control for potentiometer R102 as indicated diagramatically on the drawing.

The derivative term of the speed voltage combines electrically with the speed term voltage at the bridge output, and the combined speed voltage signal is applied to the selector circuit that is to be subsequently described. Resistors R107, R108 connected respectively between differential C101, C102 and the positive, grounded terminals of the tachometer generator are provided for the purpose of maintaining the voltage across these condensers at its equilibrium value, and eliminate switching transients.

Associated with the speed signal circuit just described, is a filter for eliminating fluctuations in the signal. These fluctuations may be of two types: Normal fluctuations due to commutator ripple in the tachometer generator,
as well as torsional engine oscillations; and abnormal fluctuations which may result from either a dirty generator or a dirty amplifier. The commutator periodically. The first type of fluctuation is characterized by relatively constant input impedance, and by not affecting the average value of the speed of the generator. 2. The second type of fluctuation is caused by the half section of the filter consisting of inductance L1 and condenser C1 in the output circuit of the generator. 3. This filter serves to greatly attenuate rapid fluctuations in voltage, and eliminates the alternating current component, leaving the direct current component unchanged. The second type of fluctuation is minimized by thermoelectrically on the drawing circuit of the generator which functions in the following manner: When the generator brushes are properly in contact with the commutator, condenser C25 will be charged fully to the speed voltage of the generator. As the generator resistance in the present control circuit is approximately 50 ohms, and condenser C25 has a capacitance of one microfarad, it will be charged with a time constant of 50 microseconds—that is, almost instantly. Assume that one brush leaves the generator commutator. Then the generator impedance is at that instant infinite. Condenser C5 must accordingly discharge through the filter and resistor R1. The effective time constant of this circuit will be of the order of one second. Thus the voltage will change only inappreciably during that time. After a second that the brush may have left the commutator. It is possible that transients of such speed may occur in the circuit. Compensation of the time constant of filter L1 C1 may be sufficient to disturb the transient balance. To avoid this effect, the filter may be moved if necessary to the output side of the derivative diode circuit. For this purpose if the filter is, it may follow the junction point of R1 R2 and R3.

Temperature control circuit

The control system according to the invention makes use of a temperature control circuit for controlling acceleration of the engine up to a predetermined percentage of the engine speed selected on the throttle T. This control is related to the instantaneous temperature of the engine as measured at the tailpipe so that the desired tailpipe temperature is maintained during acceleration.

In particular, the temperature circuit begins at a temperature sensing unit, preferably a thermocouple 3 located in the tailpipe of the engine, the function of which is to produce a control quantity dependent upon tailpipe temperature. In this case, the control quantity is a voltage generated by the thermocouple and such voltage is bucked against an adjustable datum voltage obtained from drop across the adjustable voltage source R31 and fixed resistor R30. The datum voltage is obtained from a source that derives its voltage from the inductive shunt of the operating coil 4 of a vibrating switch S38, the inductive surge being rectified by rectifier DS and filtered. The convention observed with respect to the illustration of rectifier DS as well as the other rectifiers used in the entire control system is that electron flow is in the direction of the arrow. The filtered voltage is then dropped to a neon voltage regulating tube T5 through resistor R35. The output voltage from tube T5 is further filtered and reduced by dropping it through resistors R32 in conjunction with condenser C14, and then applied to resistors R30 and R31.

The difference between the selected datum voltage and the output voltage of the thermocouple 3 is taken in a circuit constituted by a vibrating switch S3A comprising a vibrating contact reed 5 that takes on the datum voltage via a connection to the adjustable contact on resistor R31 and which works between a pair of stationary contacts 6 which are connected respectively to the ends of transistor L3. The thermocouple voltage is applied via conductor 8 to a center tap on the primary of transformer L5. Thus the difference between the voltages which appear on the vibrating contact 5 engages first one and then the other of the stationary contacts 6 7.

The corresponding outputs from both halves of the center tapped secondary of transformer L3 are amplified respectively in amplifier tubes T4 and the phase reverse of the latter applied to the end terminals of the primary of output transformer L4. The secondary of the latter has its end terminals connected to the stationary contacts 10 11 of vibratory switch S3B previously mentioned, and the amplified output constituting the instantaneous difference between the datum and thermocouple voltages is taken off through tube T13 connected to a center tap on the secondary of output transformer L4. The vibrating switches S3A and S3B are ganged together for synchronous operation, such being indicated by the broken line in the diagram connecting the vibrating reed contacts of the two switches, and hence serve to provide the desired choppings of the difference voltage at the input side of the amplifier tubes T4 and the synchronous unchopping of the amplified voltage at the output side of the amplifier so that the amplification is essentially an alternating current operation.

The chopper type amplifier is considered preferable to other known means for amplifying direct current signal voltages for various reasons and some of its advantages are discussed hereinafter in connection with the description of the main amplifier for the temperature and speed signals.

It will be noted from the circuit diagram that the other side of thermocouple 3 is connected to a bridge network of resistors R42 R43 R37 and R38. The former of two functions. Resistor R37 has a negative temperature coefficient. This is adjusted so that it gives "cold junction" compensation according to well known principles. Specifically, it causes the voltage at the ungrounded end of resistor R43 to rise 40 micro-volts for every degree centigrade rise in the temperature of resistor R37, thus giving the input voltage from thermocouple 3 with changes in ambient temperature. The second function of the bridge network will be apparent from the following: Voltage regulator tube R5 does not give perfect regulation. Should the voltage applied to this tube rise about 10% for example, the voltage at the output of tube T5 would be found to have risen about 1%. To compensate for any such error, the resistance bridge is adjusted so that the voltage at the ungrounded end of resistor R43 is, at normal ambient, 10% of the voltage taken from adjustable resistor R31 (at normal temperature datum). Then the voltage changes at resistor R31, and at the ungrounded end of resistor R43, with changes in input voltage to tube T5 will be substantially equal and thus cancel out.

Stall suppressor circuit

In the operation of jet engines, particularly at high altitudes, conditions are encountered where the compressor may surge due to stalling of the compressor blading. I have discovered that such surges may be effectively prevented by controlling the temperature of the engine exhaust gas temperature in the turbine inlet or in the turbine discharge, i.e., in the tailpipe. This is so because I have discovered that compressor stall is uniquely determined by inlet temperature, speed, and either turbine inlet or tailpipe temperature. The temperature must be scheduled as a function of the temperature of the air at the inlet to the compressor. Because the surge tendency is also a function of engine speed, the temperature schedule must also be modified according to the speed of the engine.

In Fig. 5 I have shown a series of typical curves with maximum allowable tailpipe temperature plotted against engine speed for several different temperatures of air at the compressor inlet.

At an air inlet temperature of 550° Rankine, it will be observed that the maximum allowable tailpipe gas temperature curve runs parallel with the abscissa which is to say that at all engine speeds, the allowable exhaust gas temperature is limited only by the temperature limitation of the engine, and maximum exhaust gas temperature consistent with safety limits of the engine may be employed.

At 500° Rankine, it will be observed that a lower exhaust gas temperature must be maintained up to the 75% of maximum speed mark if compressor stalling is to be prevented, but that above such speed, higher exhaust gas temperature is allowable. Points 80° Rankine where the 90% speed mark is reached the allowable engine temperature is
is no longer limited by the compressor surge factor but again by the physical temperature limitations of the engine. Thus from the 90% speed (100%) engine speed, the 550° curve coincides with the 550° curve.

At 450° Rankine, still lower exhaust gas temperatures must be preserved if stalling in the compressor is to be prevented. Examination of the 450° curve will show that while increasing temperatures are allowable at engine speeds above the 75% speed mark, the maximum allowable speed is well below the maximum temperature limitation of the engine as represented by the 550° curve.

Scheduled scheduling of temperature to prevent surging in the compressor is accomplished by superimposing an additional control factor upon the temperature circuit since the output signal from the temperature sensing unit is primarily for controlling acceleration of the engine can easily be modified to incorporate this additional scheduling factor.

Referring again to the circuit diagram shown in Fig. 2, the stall suppression section appears at the lower left corner. When for example the engine is at maximum speed, the negative output terminal of the tachometer generator will be at its most negative value with respect to ground (the positive terminal being grounded). Resistors R301 and R303, connected in circuit with the negative potentiometer terminal via lead 15, are in such a condition as determined by the adjustable tap on R302 that tap point F is now negative, so that no current flows through rectifier D302.

Assume now that the temperature at the inlet to the compressor unit 9c of the jet engine 9 is high i.e. of the order of 550° R. This temperature is sensed by a resistance unit K placed therein, and which has a highly negative temperature coefficient of resistivity. The resistance of the temperature sensing resistor K will then be relatively low. Under these conditions point G at the junction of resistors R305, R308 would have essentially the same voltage as point F, and therefore would also be negative. Rectifier D301 is, however, so polarized that it can never become negative, but only goes down to zero potential. Thus no modifying voltage will be added to that produced by the tailpipe thermocouple 3 via resistor R308 connected in circuit with the latter as seen from the input side of the amplifier unit for the temperature signal. The net result is that tailpipe temperature is scheduled in accordance with the maximum limits of the engine itself as set on the temperature datum selector (potentiometer R31).

As the engine speed decreases, point F will eventually become positive and its voltage will rise until point G conducts so that point F remains at zero potential. Since the compressor inlet temperature sensing resistor K is at a low resistance value because of the assumed high inlet temperature, point G also has essentially no voltage, and no voltage signal is applied to the tailpipe temperature input circuit via resistor R308 at any engine speed. Thus the scheduled temperature would follow the 550° curve in Fig. 5.

At a lower compressor inlet temperature for example 500° R, the temperature sensing resistor K will of course have a higher resistance due to its negative temperature coefficient. Thus when the engine speed is low, and point F is at essentially zero potential, temperature sensing resistor K and resistor R305 form a voltage divider from the +28 volt terminal to zero, giving a proportionate fraction of positive voltage at point G. This positive voltage is applied to resistor R308, and flowing through resistor R309 adds a potential divider resistor D302 starting to conduct so that point F remains at zero potential. Since the compressor inlet temperature sensing resistor K is at a low resistance value because of the assumed high inlet temperature, point G also has essentially no voltage, and no voltage signal is applied to the tailpipe temperature input circuit via resistor R308 at any engine speed. Thus the scheduled temperature would follow the 550° curve in Fig. 5.

Above this speed, the voltage at point G is lowered by the negative temperature at point F. This resistance divider 305-309 is continued by the temperature sensing thermocouple 3 in the tailpipe, which results in an overall lowered exhaust gas temperature in the tailpipe. This temperature will then remain unchanged up to the point where point F becomes negative at the 75% speed mark on the Fig. 3 curve.

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electromagnetically vibrated between two stationary contacts 19, 20. The contact reed is connected to ground and thus as it vibrates the direct current speed and temperature signal alternates and periodically grounded thus giving them an essentially alternating current characteristic. The two signals are introduced respectively into selenium rectifiers D1, D2 that are oppositely polarized with respect to the two contacts, so a variable bias voltage is applied to each of the rectifiers through the coupling resistors R4, R16. The bias voltage is obtained from a "cross-over" bridge consisting of the tachometer generator voltage, the voltage of speed control potentiometer R102, and two resistors R11, R12 so chosen that the bridge is balanced at approximately 80% of the full scale on potentiometer R102.

It will be seen that as engine speeds lower than this, the output of the cross-over bridge will be positive, so that current will flow through rectifier D2 while rectifier D1 will be cut off. Current flowing through the rectifier indicates that its impedance in the direction of current flow is fairly low and it will also transmit the essentially alternating current tempeature signal. In a similar manner, the "cross-over" bridge used without reverse, becoming negative, so that now rectifier D1 will become conducting whereas rectifier D2 will now be cut off, the effect of the essentially alternating current speed signal through rectifier D1 and block out the temperature signal at rectifier D2. Thus the selection of signal is made automatic in accordance with engine speed.

Rectifiers D1, D2 do not cut off infinitely sharply, nor exactly at zero voltage. The cut-off point is adjusted so that the overlap caused by inadequacy of the voltage in series with resistor R9, this voltage being obtained from a suitable source through resistor R10.

Main amplifier

As previously mentioned, the signals as initially developed by both the speed circuit and temperature circuit are direct current. The use of such a signal is desirable since it allows the operation of an amplifier and other forms of computation to be employed as necessary. However, the usual form of direct current amplifier is entirely unsuitable for control use. Types of direct current amplifiers previously considered include straight D.I.C., electronic amplifiers, ring modulators, and galvanometer amplifiers. The latter have taken the form of either photoelectric pick-up that form of inductive pick-up.

All the forms of amplifier suffer from a common difficulty; the balance point is not stable, and must be adjusted from time to time, thus making them unsuitable for control applications.

The amplifier about to be described has none of these drawbacks and is admirably suited to the speed control system. As mentioned in the previous section dealing with the selector circuit, the direct current speed and temperature signals are first interrupted by the vibrating switch S2A thus converting them into essentially alternating current signals which can then be amplified by a conventional alternating current amplifier. The amplifier consists of three stages T1, T2 and T3 and is arranged push-pull throughout. The first stage T1 is a pentode amplifier and acts as a phase inverter for signals introduced into either grid, the speed signal being applied through coupling condenser C5 to the grid of the upper half of the tube and the temperature signal through coupling condenser C6 to the grid of the lower half of the tube. The last stage T3 is a power amplifier, and it is in turn coupled to the output vibrating switch S2B and to the load which is constituted by a proportional solenoid 22 that controls the pilot valve 23 of a hydraulic servomotor 24 which in turn controls the supply of fuel to the jet engine.

Signals S2B like switch S2A includes a contact reed 26 electromagnetically vibrated by intermeshed coil 27 between two stationary contacts 28, 29. The contact reeds 28, 29 arranged to operate synchronously, both being preferably ganged and driven from the same vibrator coil as indicated diagrammatically on the circuit diagram and the presence switch S2B with rectify the amplifier output, giving again a direct current output signal, proportional in amplitude and in this case reversed in the sense to the input signal, but greatly amplified which signal is applied from a mid tap on the secondary of output transformer L2 to the fuel valve operating solenoid 22.

Because of the 180° relative phase reversal of the signal resulting from the use of opposed contacts of S2A for chopping the speed and temperature signals, the signals are applied to opposite grids of the push-pull input. Thus a negative (over-speed) signal and a positive (over-temperature) signal at S2A each operate to reduce fuel flow.

It will be noted that in the circuit connections 21 from the amplifier output to the proportional solenoid 22, a control switch S101A is inserted. This switch includes a contact arm 30 electrically connected to the operating coil 22c of solenoid 22 and mechanically gated to control throttle T, and which passes over an arcuate track providing alternative circuit connections to the solenoid coil. The track is sectioned providing a narrow contact segment 31 with which the contact arm 30 is engaged when the throttle T occupies its closed position, and a wide contact segment 32 engaged by the arm 30 after throttle T has been moved to any desired open position. Contact segment 32 is connected to the signal output lead 21 from transformer L2 to thus apply the speed and temperature control signals to the solenoid coils 22c. Contact segment 31 is, however, connected through re- aistor R106 to the positive terminal of the 28 volt supply line so that when the throttle is closed, positive voltage is put on the solenoid coils to thus close the fuel valve completely.

A few special features of the amplifier are well worth noting. The amplifier operates from 28 volts plate supply with no inverter, each stage of the amplifier requires some special design in the amplifier. However, as exact maintenance of input wave form is not necessary, the problem is simplified. Use of high values of grid resistor, with grid current bias, stabilizes tube characteristics. In the output stage, improved performance is possible with some negative bias on the grids. Cathode bias could be used but this would reduce the already low available plate supply. The only source of negative voltage is the tachometer generator. The grid bias used on the output stage is such that the amplifier voltage is of approximately the proper magnitude. Accordingly, the grid resistors R25, R26 of the output stage are returned via conducted 34 to the negative tachometer generator terminal.

To eliminate undesired voltage fluctuations of the +28 volt plate supply line, an RC filter consisting of resistor R39 and condenser C11 filters the plate supply to the first two stages of the amplifier. Condensers C15 and C24 are used to improve the wave form of the transmitted signal. Condenser C12 is required to absorb the inductive surge from the load of the magnetic field of generator 22 during the switching transients of the vibrating reed switch S2B.

The amplifier circuit has proved to be unusually reliable. This probably is due both to the use of the low plate supply voltage which produces a minimum of strain on the tubes, and to the uncritical nature of the amplifier. Rather wide variations in tube characteristics can be tolerated, without appreciably affecting control performance. In addition, failure of one section of either of the two latter stages will only reduce the amplifier sensitivity and output, but will not cause a complete failure.

Proportional solenoid

The proportional solenoid 22 includes an armature 22a biased to a neutral position by springs 22b that operates the piston member 22c of pilot valve 23. Cylinder 23b of the valve contains a central high pressure fluid inlet 23a, low pressure outlets 23h at each end lead to a sump, and high pressure fluid outlets 23e. 23f leading to the opposite ends of the cylinder 23b of the servomotor 24. The piston 24b of the servomotor actuates fuel valve 25 in the fuel injection line 35 leading to the jet engine 9 to control the rate of fuel flow to the combustion chambers.

The proportional solenoid 22 also includes an annular permanent magnet 22d for setting up a magnetic field which when combined with the 22a of field produces a magnetic field electromagnetically by the signal current in coils 22a produces axial movement of armature 22b in one direction or the other from its neutral position fixed by the leading springs 22c dependent upon the sense of the
current flow through these coils which in turn depends upon the polarity of the rectified output signal at output transformer L2 of the signal amplifier.

The motion associated to valve piston 23h places the high pressure inlet 23c in communication with one end of cylinder 24a of servomotor 24 and the other end of cylinder 24a in communication with one end of the low pressure outlet lines 23d causing servomotor piston 24b to shift axially and change the setting of the fuel valve 25. Movement of solenoid armature 25b in the opposite direction from its neutral position in response to an output control signal of opposite polarity will of course have an opposite effect on the setting of the fuel valve 25.

Temperature over-ride

Under normal conditions, when it is desired to accelerate from an idling to some selected running speed, the tailpipe temperature will be comparatively low and hence the temperature signal at S2A at the beginning will be strongly positive. This positive signal (after chopping) is then put through the selector circuit and amplifier and effects an opening of the fuel valve causing the engine to accelerate rapidly with an attendant rise in tailpipe temperature. Should the latter, however, rise above the datum temperature temperature selector potentiometer R31 during the period before the cross-over speed is reached, the temperature signal will swing negative, the effect of which is to cause the fuel valve to assume a more closed position.

After the cross-over speed has been reached at which instant the selector circuit cuts off the temperature signal and the fuel valve, any rise in tailpipe temperature above the selected acceleration datum value is automatically detected by a temperature over-ride circuit and the fuel rate will therefore remain constant until the temperature signal is reduced to the selected maximum. This reduction in fuel rate thus limits the acceleration rate at speeds above the cross-over speed when the derivative damping circuit could otherwise call for too high an acceleration rate. The over-ride protective circuit also comes into operation when the control is on speed governing whenever the tailpipe temperature exceeds the acceleration datum value. It also comes into operation should any abnormal condition arise such as the clogging of one or more nozzles so that excessive temperatures would be required to maintain the speed setting on the throttle.

The temperature over-ride circuit consists of a rectifier D3 transmitting a signal effectively in parallel with the normal temperature signal transformer rectifier D2. However, while rectifier D2 obtains its bias through resistor R16 from the signal selector (cross-over) circuit, the bias for the over-ride rectifier D3 is furnished from output of the thermocouple amplifier through a differentiating network consisting of resistors R55, R56 and C29. This network operates in a manner similar to the differentiating network previously described for stabilizing the temperature signal and serves to partially cancel the size delay inherent in the response characteristic of the thermocouple. The bias voltage existing at the ungrounded end of resistor R56 is applied to rectifier D3 through resistor R27. Through the time constant cancelling action of the network, the bias applied to rectifier D3 becomes negative at the same instant as the temperature signal applied to the rectifier D2 from the differentiating network, through resistor R44. Thus rectifier D3 starts to conduct at the instant the temperature signal indicates that the temperature of the exhaust gases is above the allowable datum level. Were it not for the differentiating network R55, R56, C29, the signal would not be transmitted until the actual temperature of the thermocouple had reached the datum level which because of the inherent time delay constant of the thermocouple may not occur until several seconds after the engine has reached its normal operating temperature.

As the temperature above the datum set on potentiometer R31 is reduced the trigger point at which the temperature activation is cut off.

Operation

While the operating principles of the control system have already been discussed in part in connection with the description of its component parts, a review here of the entire sequence of events which take place when the pilot of the jet propelled plane wishes to accelerate the jet engine, with reference to the speed and temperature circuits, is useful in explaining the complete operation of the system.

Referring now to Fig. 8, with the engine 9 running at an idling speed of 2700 R. P. M., the output of the cross-over bridge in the selector circuit will be negative and hence the speed of the engine is regulated in accordance with the output signal of the speed circuit applied through rectifier switch D1 and the main amplifier to the control winding 22a of the proportional solenoid 22. The speed signal will of course be zero if the engine speed agrees with the selected speed setting on potentiometer R102; if the two are in disagreement, a signal of the proper polarity to supply the necessary correction to the fuel valve 25 will be generated in the speed circuit and put through the amplifier to the fuel control solenoid 22.

With the engine running at 2700 R. P. M., the temperature in the tailpipe will normally be quite low as compared to the selected maximum level set on the temperature datum potentiometer R31. Thus, for example, if a datum level of 150° F. is selected, the tailpipe temperature may be of the order of 930° F.

Now assume that the pilot desires to increase the engine speed up to a running speed above that of the cross-over speed. When the throttle T is pushed forward and the corresponding change in the potential taken off potentiometer R102 immediately swings the output of the cross-over bridge from negative to positive it cuts off the rectifier switch D1 and puts the rectifier D2 into condition for passing control signals from the temperature circuit.

With the tail pipe temperature down about 570° F below the selected datum level, the initial signal output from the temperature circuit amplifier will be strongly positive and therefore result in a high rate of increase of fuel through valve 25 with an attendant steep rise in the tail pipe temperature and the latter soon approaches the datum temperature signal. However, as the engine continues to pick up speed, the resulting increase in the exhaust gas velocity tends to cool off the tail-pipe somewhat so that the temperature signal is maintained. That is to say, the tail pipe temperature will normally remain below the selected datum level and the fuel rate will continue to increase although at a reduced rate.

When the engine speed reaches the point where the output of the cross-over bridge in the selector circuit swings back to a negative level the rectifier switch D2 is cut off and, through the temperature signal circuit which is blocked and rectifier D1 unblocks so that the signal produced by the speed circuit is then put through the amplifier which controls the remainder of the engine acceleration until the selected speed is reached. As the engine speed approaches the selected speed, the speed signal gradually decreases to zero and the speed circuit thereafter continues to exercise control over the engine speed to maintain the latter substantially constant.

The tail pipe temperature lowers with increased engine speed and will stabilize well below the datum level after a fairly high speed is reached. In the curves of Fig. 8, it will be observed that the tail pipe temperature stabilized at about 1300° F. when the selected speed of 7800 R. P. M. was reached.

Modified stall suppressor circuit

An alternative method of scheduling acceleration of the engine to prevent compressor stall is shown in the sub-circuit diagram of Fig. 5 and its operation is predicated upon the following relations. I have discovered that the output of the pressure transducer may be operated such that if the output voltage of the transducer (assuming an axial flow construction for example) at the stall line varies as the square of the engine speed. That is, if at a speed of 1,000 R. P. M., compressor stage stalls at 1,000° C. and across the compressor, the temperature rise in the air passing through that stage may be, for example, ten degrees centigrade. Then the rise in temperature at a speed of 2,000 R. P. M., if the pressure rise across the compressor is again increased sufficiently to make this stage stall, the temperature rise will be four times
the previous value, or forty degrees centigrade. The tempera-
ture rise across several stages of the compressor may also
be employed for the above purpose. In general, con-
trolled charging of the sub-circuit diagram of Fig. 2
by means of a variable resistor. The temperature of blades
initially in various operating regimes of the engine.

With reference now to Fig. 5, it will be observed that
two sensing elements such as the thermocouples 40
and 41 are placed on each side of one of the blade rows
in the compressor 9a. These thermocouples are con-
necting directly to the signal source of Fig. 6, and will
vary with the difference in temperature across the blade
row. A small alternating current generator 42
powered by the engine in the same manner as the main
circuit 44 and 45 and in the inverse position, and the
output voltage of the generator 42 will increase as a
linear function of speed as will also the frequency.
Therefore the differentiated output voltage of the generator
will increase as the square of the engine speed. The output
of generator 42 is preferably differentiated by a
network consisting of condenser C201 and resistor R201
but any of the other well known differentiating circuits
may be employed as well, such as for example a trans-
former with a low inductance primary.

The derivative voltage across resistor R201 is recti-
fied and applied to filter 43. The output
voltage from the filter is in such sense as to buck the voltage of the thermocouples 40, 41. The net output
of this circuit is then applied to an amplifier 44 of the vibrat-
type as shown in Fig. 2 for initially amplifying the output of the ther-
ocouple in the tailpipe. For simplicity in illustration, the amplifier has accordingly been shown in one
unit only. The output of the latter is then fed through a condenser-resistor compensating network C202, R202
similar to the compensating network (resistor R51 and condenser C51) used at the output of the amplifier for
the tail pipe thermocouple voltage and which functions in
like manner to reduce the effect of the temperature
lag inherent in the thermocouples.

The output from the compensating network C202, R202
can be used in the circuit shown in Fig. 2 in place of the output from the compensating network associated with the amplified voltage signal from the tail pipe ther-
ocouple by connecting it to condenser C4 and opening
the output from the tailpipe thermocouple compensating network at resistor R44. In this way acceleration of the engine will be scheduled in accordance with tail pipe
temperature but rather along the surge line of the compressor 9a up to the cross-over speed at which the selector circuit cuts out this signal and cuts in the signal from the engine speed generator which has been shown in the scheduling to prevent marginal surge from oc-
curring.

The surge scheduling circuit of Fig. 5 is em-
ployed, protection against over temperature can be ob-
tained by using the same over-ride circuit (resistors R27,
R56, R58 and condenser C29) as is used when accelera-
tion is taking place with temperature in the tailpipe, except that in such case the stall suppressor circuit associated with thermocouple 3 in the tailpipe
would be eliminated.

Alternatively, engine acceleration may be scheduled as
a function of tailpipe temperature in the manner accord-
ing to the Fig. 2 circuit and the circuit shown in Fig. 5
used only for protection against surge. With this ar-
rangeement, the main control attempts to main
the temperature called for by the tail pipe thermocouple 3 during
acceleration, but in the event that the surge line of the compressor is reached, the temperature sensing circuit is turned off and fuel to prevent surge. One method by which this can be accomplished is shown in Fig. 6. Here the output of the compressor temperature amplifier 44 is applied to
a barrier type rectifier network R202, C202 and hence
after chopping by an additional stationary contact 45 on vbra-
tor switch S2A to the input of the main amplifier through condenser C6, resistor R60, rectifier 203 and condenser C204. The required bias for rectifier D22 is supplied in a manner similar to that shown for the tailpipe temperature over-ride con-
trol, but to a higher level in the rectifier network C206, R206 in conjunction with resistor R207.

**Modified damping circuit for speed signal**
The control circuit shown in Fig. 2 uses condensers C101, C102 and variable resistor R60 for altering the
derivative term of the speed signal as a function of speed and altitude. If desired, the modified arrangement shown
of Fig. 7 may be employed. Condensers C101, C102 are eliminated as is also the
to the fuel valve which is 

modified damping circuit for speed signal

with resistor R208. Modified damping circuit for speed signal

for altering the
derivative term of the speed signal as a function of speed and altitude. If desired, the modified arrangement shown
of Fig. 7 may be employed. Condensers C101, C102 are eliminated as is also the
to the fuel valve which is
is provided for the temperature signal. The first section is identical with that of Fig. 2 with the cross-over voltage being applied over resistor R4 and the speed signal over component C3. However, instead of applying the output of rectifier D1 directly to the input of the main amplifier, it is converted to the condenser component C5 of another rectifier circuit containing rectifier D1', resistor R6' and capacitor C5' connected in parallel with resistor R4, and rectifier D6' in series with the condenser component of said amplifier circuit. The rectified cross-over voltage will be negative, the second rectifier D1' likewise exhibits a low impedance and hence passes the speed signal. On the other hand, when the cross-over biasing voltage swings positive, the total attenuation factor of the rectifiers becomes equal to the sum of each to but to their product. Thus assuming rectifiers D1 and D2 each show an attenuation factor of thirty, the overall attenuation would not be sixty but rather nine hundred which will provide a very satisfactory control response with a large margin of safety since any leakage will then become inconsequential.

In conclusion, it is important to understand that while the invention has been described with reference to particular embodiments, various changes may be made therein without departing from the spirit and scope of the invention as defined in the appended claims. For example, while the tachometer generator is coupled to the engine providing a control voltage proportional to speed shown as a direct current machine, one of the alternating current type provided with rectifiers in its output circuit will operate equally as well. The claim:

1. In a device for controlling acceleration and speed of an engine the combination comprising: means establishing a constant reference voltage the magnitude of which is representative of a selected maximum permissible engine temperature, means producing a voltage variable with engine temperature and circuit means comparing said voltage variable and from which is produced a first control voltage variable as the difference between said compared voltages; a throttle member, means controlled by said throttle member for establishing a reference voltage variable with the throttle setting, means driven by said engine for generating a speed voltage variable with engine speed and circuit means comparing said voltages and which produces a second control voltage variable as the difference between said compared voltages; electro-responsive means controlling fuel flow to said engine; and means selectively applying said first and second control voltages to said electro-responsive means to control respectively the acceleration of said engine and the selected running speed thereof as determined by said throttle setting.

2. In a device for controlling acceleration and speed of an engine the combination comprising: means establishing a constant reference voltage the magnitude of which is representative of a selected maximum permissible engine temperature, means producing a voltage variable with engine temperature and circuit means comparing said voltage variable and from which is produced a first control voltage variable as the difference between said compared voltages; a throttle member, means controlled by said throttle member for establishing a reference voltage variable with the throttle setting, means driven by said engine for generating a speed voltage variable with engine speed and circuit means comparing said voltages and which produces a second control voltage variable as the difference between said compared voltages; means for producing a voltage variable with engine speed and circuit means comparing said voltages and which produces a second control voltage variable as the difference between said compared voltages; throttle member; means controlling fuel flow to said engine; and means selectively applying said first and second control voltages to electro-responsive means to control respectively the acceleration of said engine and the selected running speed thereof as determined by said throttle setting.

3. A device for controlling acceleration and speed of an engine the combination comprising: means establishing a constant reference voltage magnitude of which is representative of a selected maximum permissible engine temperature, means producing a voltage variable with engine temperature and circuit means comparing said voltage magnitude with engine temperature and from which is produced a first control voltage variable as the difference between said compared voltages; throttle member; means controlling fuel flow to said engine; and means selectively applying said first control voltage to electro-responsive means to control respectively the acceleration of said engine and the selected running speed thereof as determined by said throttle setting.

4. In a device for controlling acceleration and speed of an engine the combination comprising: means establishing a constant reference voltage magnitude of which is representative of a selected maximum permissible engine temperature, means producing a voltage variable with engine temperature and circuit means comparing said voltages and from which is produced a first control voltage variable as the difference between said compared voltages; throttle member; means controlling fuel admission to said engine; and means selectively applying said first control voltage to electro-responsive means to control respectively the acceleration of said engine and the selected running speed thereof as determined by said throttle setting.

5. An engine control device as defined in claim 4 and wherein said control voltage means comprises third switching means connected in parallel with said first switching means, actuation of said third switching means being controlled in accordance with the amplitude and sense of which is determined respectively by the amplitude and sense of the difference between said compared voltages; engine speed; and circuit means comparing said voltages and which produces a second control voltage variable as the difference between said compared voltages; throttle member; means controlling fuel admission to said engine; and means selectively applying said first and second control voltages to electro-responsive means to control respectively the acceleration of said engine and the selected running speed thereof as determined by said throttle setting.

6. In a device for controlling speed and acceleration of a combustion gas turbine engine of the type including coupled turbine and multi-stage compressor units and a combustion chamber unit therebetween, the combination comprising: means producing a signal voltage variable as the engine speed and circuit means comparing said voltage variable with engine speed and from which is produced a first control voltage variable, means producing a speed voltage variable with engine speed and circuit means comparing said voltage variable with engine speed and from which is produced a second control voltage variable as the difference between said compared voltages; a throttle member; means controlling fuel admission to said engine; and means selectively applying said first and second control voltages to electro-responsive means to control respectively the acceleration of said engine and the selected running speed thereof as determined by said throttle setting.

7. In a device for controlling speed and acceleration of a combustion gas turbine engine of the type including coupled turbine and multi-stage compressor units and a combustion chamber unit therebetween, the combination comprising: means producing a signal voltage variable as the engine speed and circuit means comparing said voltage variable with engine speed and from which is produced a first control voltage variable, means producing a speed voltage variable with engine speed and circuit means comparing said voltage variable with engine speed and from which is produced a second control voltage variable as the difference between said compared voltages; a throttle member; means controlling fuel admission to said engine; and means selectively applying said first and second control voltages to electro-responsive means to control respectively the acceleration of said engine and the selected running speed thereof as determined by said throttle setting.
the square of engine speed and circuit means comparing said voltages to produce a third control voltage which is representative of a selected maximum permissible combustion gas temperature, circuit means comparing said voltages and which produces a control voltage variable as their difference, means responsive to said control voltage for rendering said control voltage ineffective when a predetermined engine speed has been reached, and speed dependent means effective at engine speeds above said predetermined speed to schedule fuel admission to said engine.

11. In a device for controlling acceleration of a combustion gas turbine engine of the type including coupled turbine and compressor units and a combustion chamber therebetween, the combination comprising, means producing a signal voltage variable with the temperature of the combustion gases, signal modifying means including a temperature sensing device responsive to air temperature at the air inlet to said compressor unit for effecting an apparent increase in said signal voltage upon a decrease in compressor air inlet temperature, means establishing a constant reference voltage the magnitude of which is representative of a selected maximum permissible combustion gas temperature, circuit means comparing said voltages and which produces a control voltage variable as their difference, and means responsive to said control voltage for scheduling fuel admission to said combustion chamber unit in accordance with the amplitude of said control voltage.

12. An engine control device as defined in claim 11 in which said signal modifying means also includes means responsive to engine speed for likewise effecting an apparent increase in said signal voltage upon a decrease in speed.

13. In a device for controlling acceleration of a combustion gas turbine engine of the type including coupled turbine and compressor units and a combustion chamber unit therebetween, the combination comprising, means producing a first signal voltage variable with the temperature of the combustion gases, means including a temperature sensing device responsive to air temperature at the air inlet to said compressor unit for producing a second signal voltage variable inversely as the change in air temperature at said compressor inlet, means establishing a constant reference voltage the magnitude of which is representative of a selected maximum permissible combustion gas temperature, circuit means comparing said voltages and which produces a control voltage variable as their difference between said reference voltage and the sum of said first and second signal voltages, and means responsive to said control voltage for scheduling fuel admission to said combustion chamber unit in accordance with the amplitude of said control voltage.

14. In a device for controlling acceleration of a combustion gas turbine engine of the type including coupled turbine and compressor units and a combustion chamber unit therebetween, the combination comprising, means producing a first signal voltage variable with the temperature of the combustion gases, means including a temperature sensing device responsive to air temperature at the air inlet to said compressor unit and a device responsive to engine speed for producing a second signal voltage variable inversely as the change in engine speed and also inversely as the change in air temperature at said compressor inlet, means establishing a constant reference voltage the amplitude of which is representative of a selected maximum permissible combustion gas temperature, circuit means comparing said voltages and which produces a control voltage variable as the difference between said reference voltage and the sum of said first and second signal voltages, and means responsive to said control voltage for scheduling fuel admission to said combustion chamber unit in accordance with the amplitude of said control voltage.

15. In a device for controlling acceleration of a combustion gas turbine engine of the type including coupled turbine and multi-stage compressor units and a combustion chamber unit therebetween, the combination comprising, means producing a signal voltage variable with the temperature of the combustion gases, circuit means establishing a constant reference voltage the magnitude of which is representative of a selected maximum permissible combustion gas temperature, circuit means comparing said voltages and which produces a control voltage variable as their difference, means responsive to said control voltage for rendering said control voltage ineffective when a predetermined engine speed has been reached, and speed dependent means effective at engine speeds above said predetermined speed to schedule fuel admission to said engine.
responsive to said control voltage for scheduling fuel admission to said combustion chamber unit in accordance with the amplitude of said control voltage.

16. In a device for controlling acceleration of a combustion gas turbine engine of the type including coupled turbine and multi-stage compressor units and a combustion chamber therebetween, said throttle member being driven by said engine and which produces a voltage whose amplitude and frequency both vary as a linear function of engine speed, circuit means differentiating the output voltage of said generator to produce a second signal voltage which therefore varies as the square of engine speed, circuit means comparing said first and second signal voltages to produce a control voltage variable as their difference, and means responsive to said control voltage for scheduling fuel admission to said combustion chamber unit in accordance with the amplitude of said control voltage.

17. In a device for controlling the speed of an aircraft propelled by a combustion gas turbine engine of the type including coupled turbine and compressor units, and a combustion chamber therebetween; a throttle member, means controlled by said throttle member for producing a reference variable voltage with the throttle setting, means generating a signal voltage variable as a function of engine speed, a differentiating circuit having an adjustable time constant connected to said voltage generating means for producing a derivative voltage variable as the rate-of-change of said signal voltage, means controlled by said throttle member for shortening the time constant of said differentiating circuit as said throttle member is moved to a more open position and vice versa, circuit means comparing said voltages and which produces a control voltage variable as the difference between said reference voltage and the sum of said signal voltage and its derivative term, and means responsive to said control voltage for scheduling fuel admission to said combustion chamber unit in accordance with the amplitude of said control voltage.

18. In a device for controlling the speed of an aircraft propelled by a combustion gas turbine engine of the type including coupled turbine and compressor units, a combustion chamber therebetween and a fuel valve controlling admission of fuel to said chamber; a throttle member, means controlled by said throttle member for producing a reference voltage variable with the throttle setting, means generating a speed voltage variable as a linear function of engine speed, a differentiating circuit having an adjustable time constant connected to said voltage generating means for producing a derivative voltage variable as the rate-of-change of said signal voltage, means controlled by said fuel valve for shortening the time constant of said differentiating circuit as said fuel valve is moved to a more open position and vice versa, circuit means comparing said voltages and which produces a control voltage variable as the difference between said reference voltage and the sum of said signal voltage and its derivative term, and means responsive to said control voltage for actuating said fuel valve in accordance with the amplitude of said control voltage.

19. In a device for controlling the speed of an aircraft propelled by a combustion gas turbine engine of the type including coupled turbine and compressor units and a combustion chamber therebetween; a throttle member, means controlled by said throttle member for producing a reference voltage variable with the throttle setting, means generating a speed voltage variable as a linear function of engine speed, a differentiating circuit having an adjustable time constant connected to said voltage generating means for producing a derivative voltage term variable as the rate-of-change of said speed voltage, means controlling by said throttle member for shortening the time constant of said differentiating circuit as said throttle member is moved to a more open position and vice versa, means producing an error voltage signal from comparing said control signal with the actual engine speed, means comparing said signals and which produces a control voltage variable as the difference between said reference voltage and the sum of said speed voltage and its derivative term, and means responsive to said control voltage for scheduling fuel admission to said combustion chamber unit in accordance with the amplitude of said control voltage.

20. In a device for controlling the speed of an aircraft propelled by a combustion gas turbine engine of the type including coupled turbine and compressor units, a combustion chamber unit therebetween and an electro-responsive slide valve admitting fuel to said combustion chamber; a throttle member, means controlled by said throttle member for producing a reference voltage, a signal producing means for producing a second signal voltage variable as a linear function of engine speed, a differentiating circuit connected to said voltage generating means for producing a control voltage variable as the rate-of-change of said speed voltage, means comparing said voltages and which produces a control voltage for actuating said control valve and its derivative term, and means responsive to said control voltage for scheduling fuel admission to said combustion chamber unit in accordance with the amplitude of said control voltage.

21. In a device for controlling the speed of an aircraft propelled by a combustion gas turbine engine of the type including coupled turbine and compressor units, and a combustion chamber therebetween, said device comprising means producing a first signal variable with the temperature rise across at least one stage in the compressor unit, means producing a second signal variable as the square of actual engine speed, means comparing said first and second signals to produce a control signal variable with the difference between said signals and means responsive to said control signal variable for scheduling admission of fuel to said combustion chamber, and means responsive to the speed of said engine for applying only said first control signal to said fuel scheduling means, said control means including a predetermined fraction of said selected running speed and similarly applying only said second control signal at engine speeds above said predetermined fraction.

22. In a device as defined in claim 21 where further includes means modifying said first control signal as a function of air temperature at the air inlet to the compressor unit of said engine.

23. In a device for controlling acceleration of a combustion gas turbine engine of the type including coupled turbine and multi-stage compressor units and a combustion chamber therebetween; a device comprising means producing a first signal variable with the temperature rise across at least one stage in the compressor unit, means producing a second signal variable as the square of actual engine speed, means comparing said first and second signals to produce a control signal variable with the difference between said control signals and means responsive to said control signal variable for scheduling admission of fuel to said combustion chamber, and means responsive to engine speed for applying only said first control signal to said fuel scheduling means at engine speeds below a predetermined fraction of said selected running speed and similarly applying only said second control signal at engine speeds above said predetermined fraction.

24. In a device for controlling acceleration of a combustion gas turbine engine of the type including coupled turbine and multi-stage compressor units and a combustion chamber therebetween, said device comprising means producing a first signal variable with the temperature rise across at least one stage in the compressor unit, means producing a second signal variable as the square of actual engine speed, means comparing said signals and which produces a control signal variable with the difference between said signals and means responsive to said control signal variable for scheduling admission of fuel to said combustion chamber.

25. In a device for controlling the speed of an aircraft propelled by a combustion gas turbine engine of the type including coupled turbine and compressor units and a combustion chamber therebetween, said device comprising means producing a first signal proportional to actual
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21. A device for controlling the speed of a combustion engine comprising a combustion gas turbine engine of the type including connected turbine and compressor units and a combustion chamber therebetween, said engine comprising means for producing a control signal variable as the difference between the actual temperature of said engine and the temperature of the combustion gases, means responsive to the speed of said engine for applying only said first control signal to said fuel scheduling means at engine speeds above a predetermined fraction of said selected running speed and similarly applying only said second control signal to said fuel scheduling means at engine speeds below said predetermined fraction of said selected running speed variable as the difference between the actual temperature of said engine and the temperature of the combustion gases, means responsive to the speed of said engine for applying only said first control signal to said fuel scheduling means at engine speeds above a predetermined fraction of said selected running speed and similarly applying only said second control signal to said fuel scheduling means at engine speeds below said predetermined fraction of said selected running speed. 

22. A device for controlling the acceleration from idling speed of a combustion gas turbine engine of the type including connected turbine and compressor units and a combustion chamber therebetween, means comprising means for producing a control signal variable as the difference between the actual temperature of said engine and the temperature of the combustion gases, means responsive to the speed of said engine for applying only said first control signal to said fuel scheduling means at engine speeds below said predetermined fraction of said selected running speed and similarly applying only said second control signal to said fuel scheduling means at engine speeds above said predetermined fraction of said selected running speed. 

23. A device for controlling the acceleration from idling speed of a combustion gas turbine engine of the type including connected turbine and compressor units and a combustion chamber therebetween, means comprising means for producing a control signal variable as the difference between the actual temperature of said engine and the temperature of the combustion gases, means responsive to the speed of said engine for applying only said first control signal to said fuel scheduling means at engine speeds below said predetermined fraction of said selected running speed and similarly applying only said second control signal to said fuel scheduling means at engine speeds above said predetermined fraction of said selected running speed. 

24. A device for controlling the acceleration from idling speed of a combustion gas turbine engine of the type including connected turbine and compressor units and a combustion chamber therebetween, means comprising means for producing a control signal variable as the difference between the actual temperature of said engine and the temperature of the combustion gases, means responsive to the speed of said engine for applying only said first control signal to said fuel scheduling means at engine speeds below said predetermined fraction of said selected running speed and similarly applying only said second control signal to said fuel scheduling means at engine speeds above said predetermined fraction of said selected running speed. 

25. A device for controlling the acceleration from idling speed of a combustion gas turbine engine of the type including connected turbine and compressor units and a combustion chamber therebetween, means comprising means for producing a control signal variable as the difference between the actual temperature of said engine and the temperature of the combustion gases, means responsive to the speed of said engine for applying only said first control signal to said fuel scheduling means at engine speeds below said predetermined fraction of said selected running speed and similarly applying only said second control signal to said fuel scheduling means at engine speeds above said predetermined fraction of said selected running speed. 

26. A device for controlling the speed of an engine comprising a combustion gas turbine engine of the type including connected turbine and compressor units and a combustion chamber therebetween, means comprising means for producing a control signal variable as the difference between the actual temperature of said engine and the temperature of the combustion gases, means responsive to the speed of said engine for applying only said first control signal to said fuel scheduling means at engine speeds below said predetermined fraction of said selected running speed and similarly applying only said second control signal to said fuel scheduling means at engine speeds above said predetermined fraction of said selected running speed. 

27. A device for controlling the speed of an engine comprising a combustion gas turbine engine of the type including connected turbine and compressor units and a combustion chamber therebetween, means comprising means for producing a control signal variable as the difference between the actual temperature of said engine and the temperature of the combustion gases, means responsive to the speed of said engine for applying only said first control signal to said fuel scheduling means at engine speeds below said predetermined fraction of said selected running speed and similarly applying only said second control signal to said fuel scheduling means at engine speeds above said predetermined fraction of said selected running speed. 

28. A device for controlling the acceleration and speed of an engine comprising means producing a first control signal variable as the difference between the actual temperature of said engine as compared with a predetermined maximum permissible temperature, means producing a second control signal as the difference between the actual temperature of said engine and the temperature of the combustion gases, means responsive to the speed of said engine for applying only said first control signal to said fuel scheduling means at engine speeds below a predetermined fraction of said selected running speed and similarly applying only said second control signal to said fuel scheduling means at engine speeds above said predetermined fraction of said selected running speed. 

29. A device for controlling the acceleration and speed of an engine comprising means producing a first control signal variable as the difference between the actual temperature of said engine as compared with a predetermined maximum permissible temperature, means producing a second control signal as the difference between the actual temperature of said engine and the temperature of the combustion gases, means responsive to the speed of said engine for applying only said first control signal to said fuel scheduling means at engine speeds below a predetermined fraction of said selected running speed and similarly applying only said second control signal to said fuel scheduling means at engine speeds above said predetermined fraction of said selected running speed. 

30. A device for controlling the acceleration and speed of an engine comprising means producing a first control signal variable as the difference between the actual temperature of said engine as compared with a predetermined maximum permissible temperature, means producing a second control signal as the difference between the actual temperature of said engine and the temperature of the combustion gases, means responsive to the speed of said engine for applying only said first control signal to said fuel scheduling means at engine speeds below a predetermined fraction of said selected running speed and similarly applying only said second control signal to said fuel scheduling means at engine speeds above said predetermined fraction of said selected running speed. 

31. A device for controlling the acceleration and speed of an engine comprising means producing a first control signal variable as the difference between the actual temperature of said engine as compared with a predetermined maximum permissible temperature, means producing a second control signal as the difference between the actual temperature of said engine and the temperature of the combustion gases, means responsive to the speed of said engine for applying only said first control signal to said fuel scheduling means at engine speeds below a predetermined fraction of said selected running speed and similarly applying only said second control signal to said fuel scheduling means at engine speeds above said predetermined fraction of said selected running speed. 

32. A device for controlling the acceleration and speed of an engine comprising means producing a first control signal variable as the difference between the actual temperature of said engine as compared with a predetermined maximum permissible temperature, means producing a second control signal as the difference between the actual temperature of said engine and the temperature of the combustion gases, means responsive to the speed of said engine for applying only said first control signal to said fuel scheduling means at engine speeds below a predetermined fraction of said selected running speed and similarly applying only said second control signal to said fuel scheduling means at engine speeds above said predetermined fraction of said selected running speed. 

33. A device for controlling the acceleration and speed of an engine comprising means producing a first control signal variable as the difference between the actual temperature of said engine as compared with a predetermined maximum permissible temperature, means producing a second control signal as the difference between the actual temperature of said engine and the temperature of the combustion gases, means responsive to the speed of said engine for applying only said first control signal to said fuel scheduling means at engine speeds below a predetermined fraction of said selected running speed and similarly applying only said second control signal to said fuel scheduling means at engine speeds above said predetermined fraction of said selected running speed. 

34. A device for controlling the acceleration and speed of an engine comprising means producing a first control signal variable as the difference between the actual temperature of said engine as compared with a predetermined maximum permissible temperature, means producing a second control signal as the difference between the actual temperature of said engine and the temperature of the combustion gases, means responsive to the speed of said engine for applying only said first control signal to said fuel scheduling means at engine speeds below a predetermined fraction of said selected running speed and similarly applying only said second control signal to said fuel scheduling means at engine speeds above said predetermined fraction of said selected running speed. 

35. A device for controlling the acceleration and speed of an engine comprising means producing a first control signal variable as the difference between the actual temperature of said engine as compared with a predetermined maximum permissible temperature, means producing a second control signal as the difference between the actual temperature of said engine and the temperature of the combustion gases, means responsive to the speed of said engine for applying only said first control signal to said fuel scheduling means at engine speeds below a predetermined fraction of said selected running speed and similarly applying only said second control signal to said fuel scheduling means at engine speeds above said predetermined fraction of said selected running speed. 

36. A device for controlling the acceleration and speed of an engine comprising means producing a first control signal variable as the difference between the actual temperature of said engine as compared with a predetermined maximum permissible temperature, means producing a second control signal as the difference between the actual temperature of said engine and the temperature of the combustion gases, means responsive to the speed of said engine for applying only said first control signal to said fuel scheduling means at engine speeds below a predetermined fraction of said selected running speed and similarly applying only said second control signal to said fuel scheduling means at engine speeds above said predetermined fraction of said selected running speed. 

37. A device for controlling the acceleration and speed of an engine comprising means producing a first control signal variable as the difference between the actual temperature of said engine as compared with a predetermined maximum permissible temperature, means producing a second control signal as the difference between the actual temperature of said engine and the temperature of the combustion gases, means responsive to the speed of said engine for applying only said first control signal to said fuel scheduling means at engine speeds below a predetermined fraction of said selected running speed and similarly applying only said second control signal to said fuel scheduling means at engine speeds above said predetermined fraction of said selected running speed. 

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(Corresponding Great Britain 601,107, Apr. 28, 1948.)