# United States Patent [19]

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[54] **MISSILE DIRECTIONAL CONTROL SYSTEM**

[75] Inventor: **Robert F. May**, Birmingham, Mich.

[73] Assignee: **Chrysler Corporation**, Highland Park, Mich.

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[52] **U.S. Cl.** .............................................. **244/3.22**

[51] **Int. Cl.** .............................................. **F42b 15/02**

[58] **Field of Search** .................... 244/14, 14.1–14.6, 244/77 A, 77 D, 79; 102/50; 313/489

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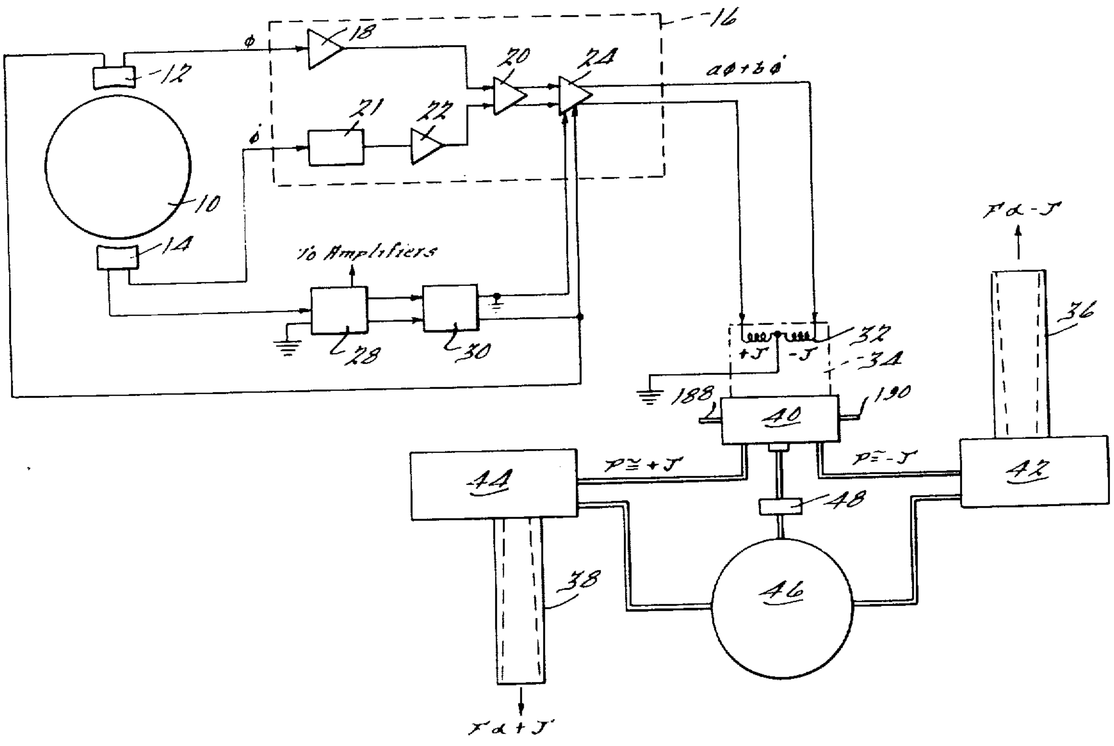
*Primary Examiner*—Verlin R. Pendegrass
*Attorney, Agent, or Firm*—Talburtt & Baldwin

## EXEMPLARY CLAIM

1. An attitude control system for maintaining a missile on a launch predetermined path comprising means mounted on the missile for indicating a deviation from said predetermined path including means for providing an output signal representative of angular position change and means for providing an output signal representative of angular rate change, means for modifying said angular position change signal by multiplying it by a factor "*a*" whereby a ≅[(T-D)/(k/p) - 1], an algebraic summation means responsive to said modified position and rate change signals and operable to provide a combined output representative of their algebraic summation, and means operatively connected to and controlled by the output of said summation means, said last mentioned means operable to provide a corrective fotce to return the missile to its predetermined path.

**16 Claims, 9 Drawing Figures**



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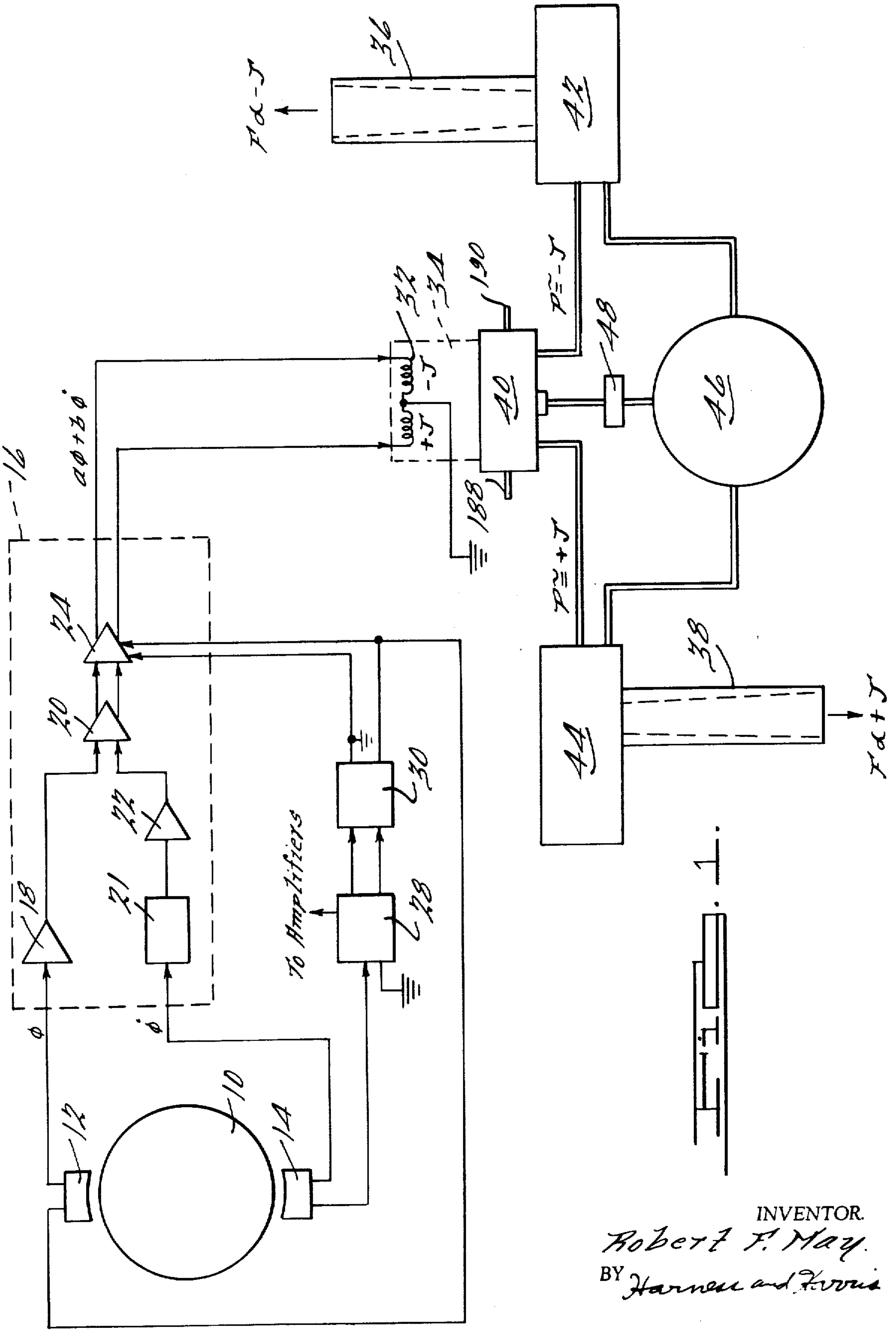
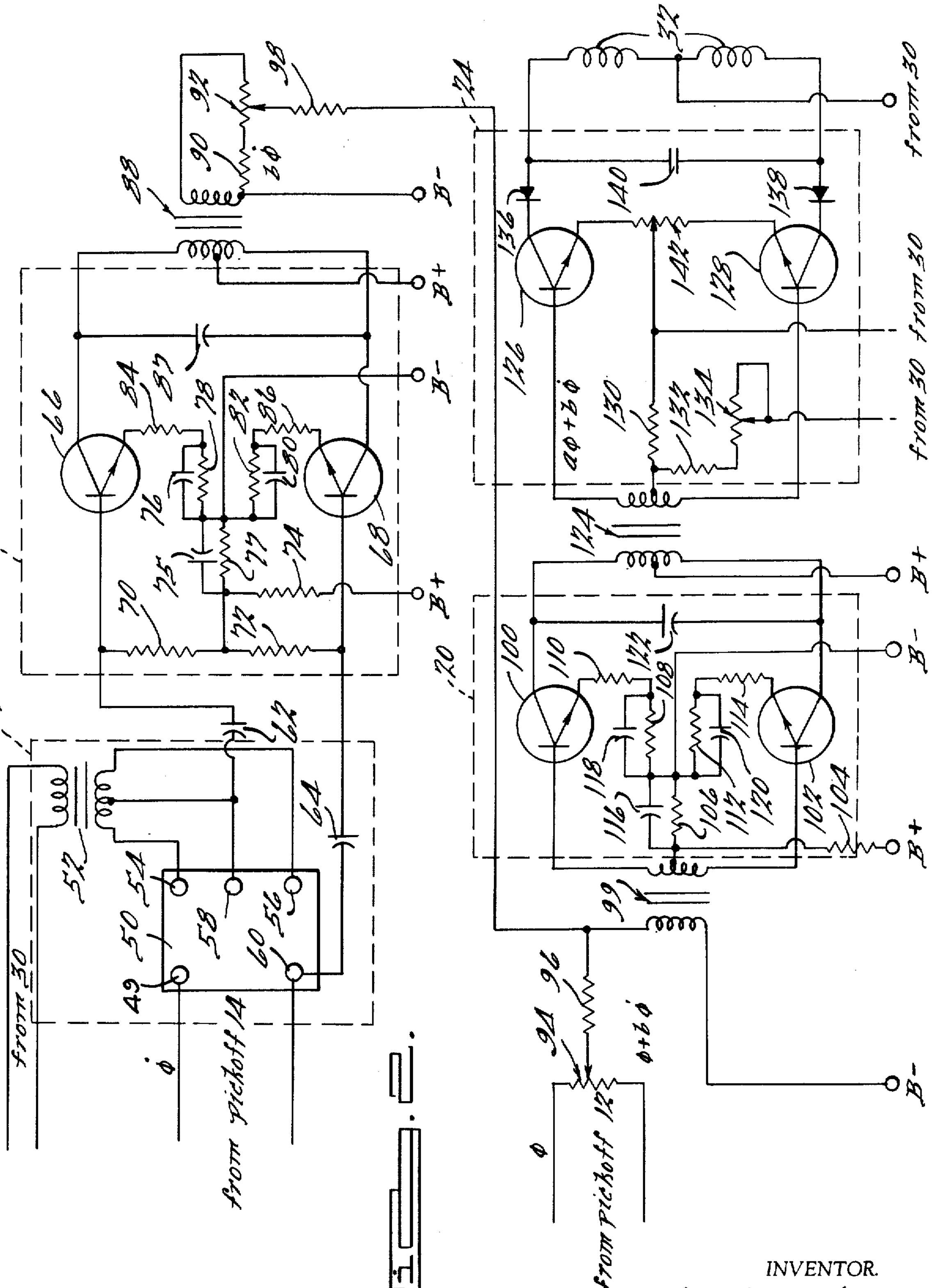


FIG. 1.

INVENTOR.
Robert F. May
BY Harness and Harris

ATTORNEY.



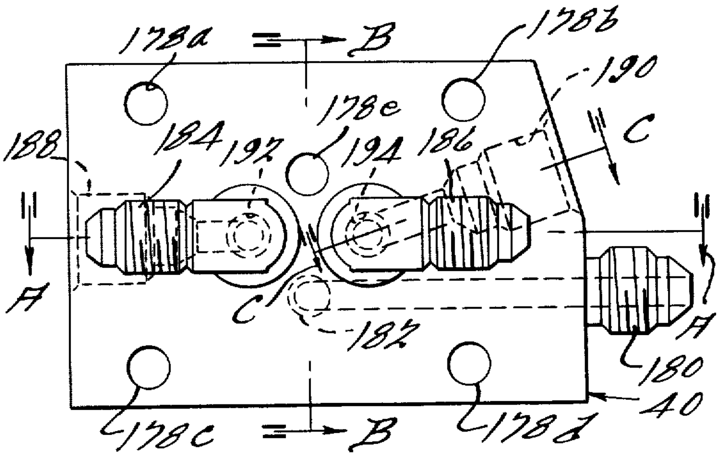
INVENTOR.

Robert F. May

BY

Harness and Harris

ATTORNEY



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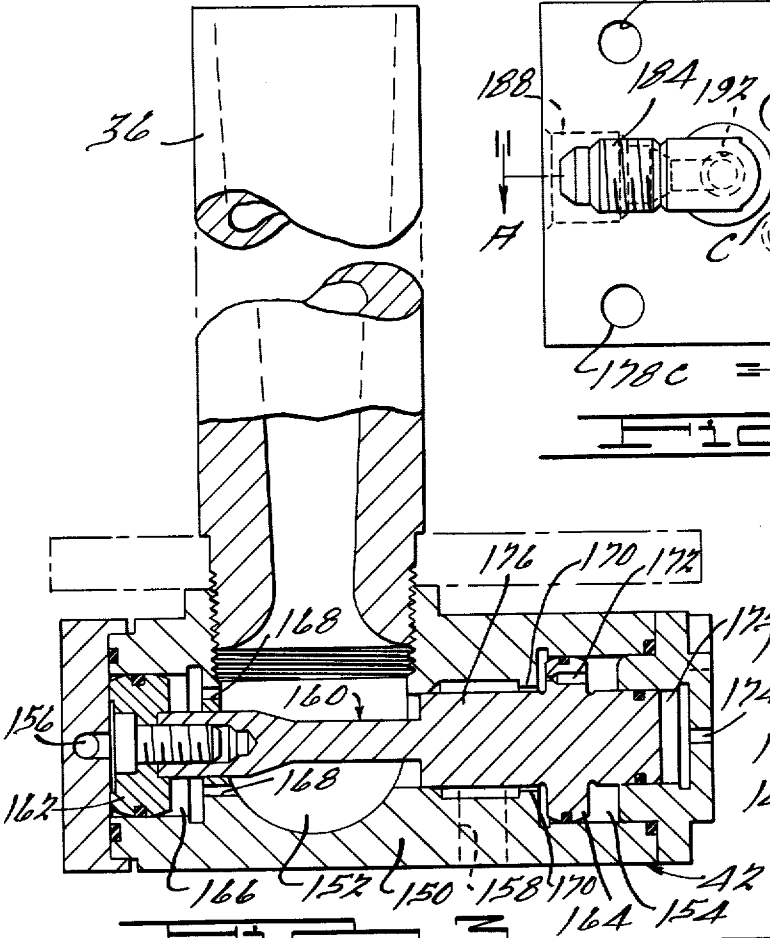

FIG. 3.

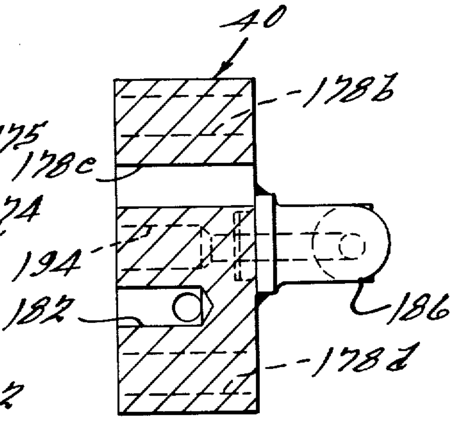

FIG. 6.

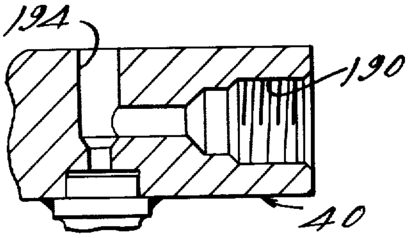

FIG. 7.

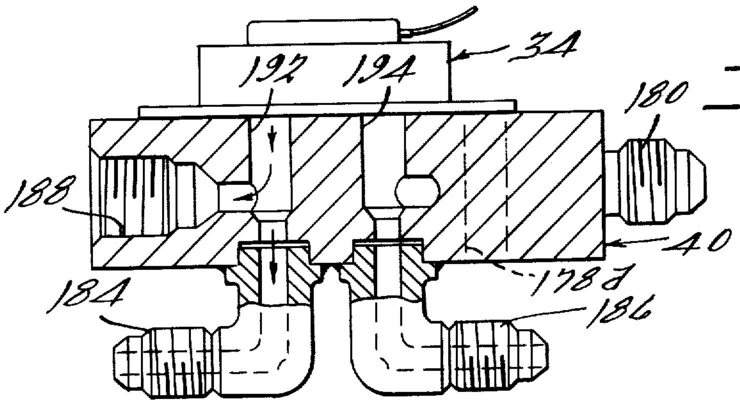

FIG. 5.

INVENTOR.

Robert F. May

BY Harness and Harris

ATTORNEY.

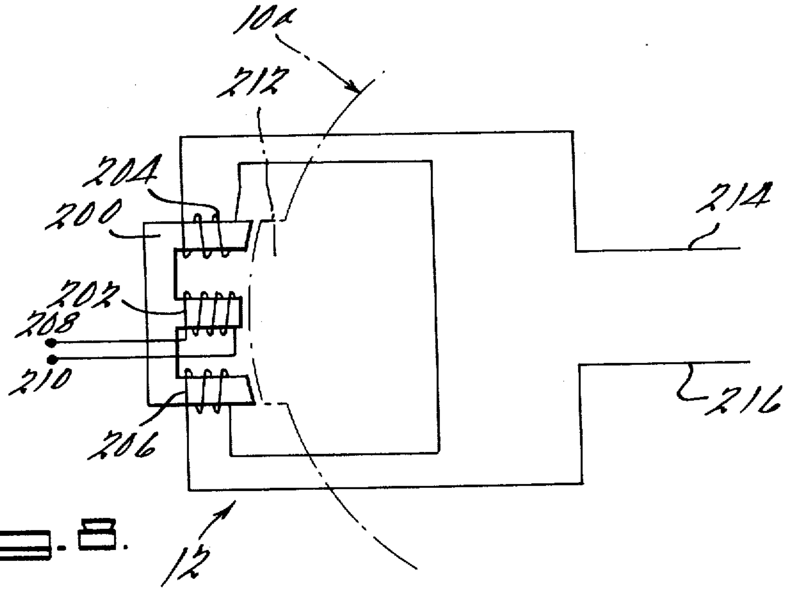

FIG. 8.

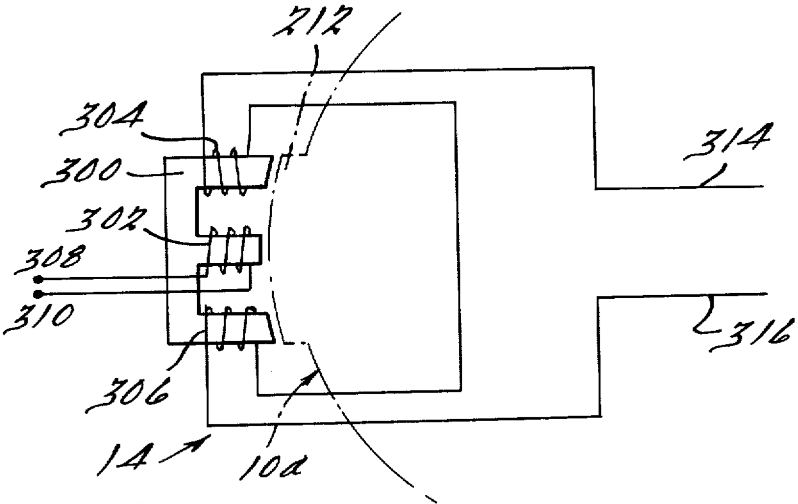

FIG. 9.

INVENTOR.
Robert F. May
BY
Harness and Harris
ATTORNEYS.

## MISSILE DIRECTIONAL CONTROL SYSTEM

This invention relates generally to missile directional control systems and, more particularly, to a directional control system to provide missile guidance during its high acceleration boost flight.

In provision of a directional control system, a primary requirement is that the missile be aligned in the correct direction of travel at the end of boost flight. Otherwise stated, there should be no velocity or displacement perpendicular to the direction in which the missile was initially aimed and launched. The boost flight phase may then be followed by free flight, subject to ballistic wind effects, or it can be followed by a controlled sustained flight. When the directional control system is utilized during the entire missile flight, the primary requirement is that the lateral displacement at the end of flight be held to an absolute minimum.

It is an object of the present invention to provide a directional control system operable without external control data and utilizing body-fixed attitude angle and angular rate information to exercise its control function.

It is an additional object of this invention to provide a directional control system and control method which requires no missile spin for stability of operation but is operable in the presence of such spin.

It is a further object of this invention to provide a directional control system providing attitude corrective thrust forces of substantially linear variation with exceedingly short time lag behind the initiating error signal.

The above objects are best realized by a directional control system which measures the pitch and yaw of a missile which is aerodynamically stable through the Mach number range under which it operates under directional control and then applies torques to restrain this motion in such a manner that motor thrust forces, aerodynamic forces and control forces remain balanced in directions perpendicular to the flight path. The present invention, first briefly described, comprises a simple two-degree-of-freedom gyroscope, capable of operation under high acceleration and mounted with its spin axis along the missile longitudinal axis. Electrical outputs are taken from gyro pick-offs which are representative of angular deviation and rate of deviation of the missile body with respect to the spin axis. These outputs are utilized in an electronic computer which linearly combines this data and produces an electrical control output. Control jets are fixed to the missile in the same body plane as the gyro pick-offs and are adapted to provide corrective forces normal to the missile body. The electrical control output is employed to direct corrective forces through these jets into the airstream or, alternately, into the boost rocket nozzle.

To facilitate the understanding of the present invention, it may be characterized as being of the open-loop type i.e., one in which no direct measurement is made of the lateral velocity or displacement of the missile flight path which is to be minimized. The control gains are functions of aerodynamic characteristics, thrust level, and missile geometry. By straightforward static analysis, it will be seen that the magnitude of the control force is proportional to the quantity (thrust minus longitudinal drag) times the pitch or yaw angle measured by the gyro, divided by the quantity (ratio of control moment arm to aerodynamic moment arm) minus

1 and the control equation may be expressed as follows:

$$J = [T - D)/k/P - 1] = \phi$$

in which

J = control force
T = thrust
D = drag
k = control moment arm
P = aerodynamic moment arm
$\phi$ = pitch or yaw angle
$a$ = gain coefficient

Under conditions of boost acceleration and high thrust the T-D term is relatively constant. As the missile propellant is used up, $k$ varies with the changing missile weight. The quantity $p$ varies with the Mach number.

It will be observed that the above control equation is undamped. It is desirable to incorporate a rate term to provide a damping function to render the control force a function of both the angular term and an angular rate term as follows:

$J = a\,\phi + b\,\phi'$ in which $b\,\phi'$ is the angular rate term. The angular rate term $b\,\phi'$ is a function of missile inertia and control transfer function.

In the presence of a missile roll, a cross coupling exists between the pitch and yaw controls due to a roll effect on angular rate. If the missile roll is significant, the control equation may be modified to include a third term $c\,e'\phi$ as follows:

$$J = a\,\phi + b\,\phi' + c\,e'\theta$$

in which

c = gain coefficient
$e'$ = roll angular rate
$\theta$ = gyro angle in the other channel

It should be noted that the term $\theta$ refers to pitch angle for the yaw control channel or to negative yaw angle for the pitch control channel. It is generally desirable to utilize constant values for $a$, $b$, and $c$ rather than to program each, although employment of a program may be made to increase flight path accuracy.

In view of the foregoing objects and comments, further understanding of the present invention will become apparent from a consideration of the accompanying specifications and drawings in which

FIG. 1 is a functional block diagram of the directional control system incorporating the present invention;

FIG. 2 is a schematic drawing of the electronic computer which performs the operations defined by the control equations previously noted;

FIG. 3 is a cross sectional view of the servo regulator valve utilized;

FIG. 4 is a bottom plan view of the manifold block utilized in combination with the servo valve of FIG. 3;

FIG. 5 is a sectional view taken along the line A—A of FIG. 4 and includes a diagrammatic showing of the servo valve in its operative relationship to the manifold block;

FIG. 6 is a sectional view taken along the line B—B of FIG. 4; and

FIG. 7 is a sectional view taken along the line C—C of FIG. 4;

FIG. 8 is a schematic drawing of position pickoff 12; and

FIG. 9 is a schematic drawing view of a rate pickoff 14.

In FIG. 1, a control system for a missile is shown with reference to one plane of control, as for example, in the pitch plane. It will be noted that in the practice of the present invention an additional system would be employed in the yaw control plane also, which would be essentially a duplicate of the system hereinafter shown and described. Included as an element of this system is a gyroscope **10** which may be a two degree-of-freedom gyroscope capable of operation under high acceleration and mounted with its spin axis along the missile longitudinal axis. Gyroscope **10** may be of the spherical air bearing type with the inertial element, namely, its rotor, external to the bearing. An angular position pickoff **12** and an angular rate pickoff **14** are located at spaced points on the periphery of the rotating inertial element and are operable to provide electrical outputs representative of the magnitude of angular position and angular rate changes, respectively. The outputs from pickoffs **12** and **14** are fed into an electronic computer **16.** More specifically, the output from position pickoff **12** may be directed through a pre-amplifier **18** into a summing amplifier **20.** The output from rate pickoff **14** is directed through a modulator **21** and pre-amplifier **22** to summing amplifier stage **20.** The summed signal outputs from summing amplifier **20** pass through a demodulator **24.** A D.C. power source **28** is utilized to furnish power for the several aforementioned amplifiers and stages utilized in the system. A static inverter **30** is utilized to provide a constant reference signal to demodulator **24** and for excitation of the position pickoffs. The amplified d.c. outputs are then directed in the form of pulses of plus or minus polarity to the control coils **32** of servo valve **34.** Depending on whether the control signal output of the computer **16** is plus or minus, one of the oppositely oriented thrust jets **36,38** will be operated with a corrective force F of the appropriate magnitude. Thrust jets **36,38** are controlled in their action by servo valve **34.** a manifold block **40** operatively associated therewith, and servo regulators **42** and **44,** respectively. The operating pressure for servo valve **34** and servo regulators **42,44** are derived from a common source of pressurized fluid **46.** Inserted in the line between servo valve **34** and pressure source **46** is a regulator valve **48** of a type well known in the art whose function is to maintain a constant pressure output to servo valve **34** independent of the diminution of pressure in source **46.** The thrust from jets **36** and **38** is thus controlled as a linear function of the electrical control signal from computer **16** by means of the servo system comprising servo valve **34,** manifold block **40,** and servo regulators **42,44.** It should be noted that jets **36** and **38** are oriented to provide precisely controllable thrust forces normal to the missile longitudinal axis and are located in the same longitudinal plane as the angular position and rate pickoffs **12** and **14.** Jets **36** and **38** may be directed outwardly into the airstream or inwardly in the rocket booster nozzle, and can eject gas in the former case, or gas or propellant in the latter. Control can also be maintained by other means well known in the art such as by vanes in the rocket booster exit or by air vanes. In the present embodiment pneumatic jets are utilized, directed out into the airstream.

FIG. **2** shows a schematic of the control computer **16** which is a semiconductor circuit with the basic function of conditioning the outputs of the pickoffs **12** and **14** for proportional control of servo valve **34.** Pickoff **12** is an angular position pickoff whose output is provided as a suppressed carrier modulated signal with the modulation being the angular position error as reflected in gyro **10.** Pickoff **14** is an inductive rate pickoff whose output signal is proportional to the rate (degrees per unit time) of the angular error as reflected by the gyro **10.** These signals form the inputs to computer **16** as shown with $\phi$ being the term for position $\phi'$ the term for rate. The $\phi'$ signal is amplified or multiplied by a constant term $b$ in amplifiers **18** and **22,** respectively. Both signals are added in summing amplifier **20** to perform the step $a\ \phi + b\ \phi'$ which combined output is further amplified in demodulator **24** to provide a control current output to the coil **32** of servo valve **34** which control current is proportional to the error or deviation experienced by the missile in its boost flight from the launch predetermined flight. D.C. source **28** furnishes the B + and B — biases as required for operation of the computer circuitry. The rate signal input $\phi'$ is fed as an input to input terminal **49** of a solid state chopper **50** which may be a solid state chopper such as that currently commercially available from the Solid State Electronic Corporation of Van Nuys, California as their Model No. 70. Chopper **50** is driven by a 400 cps reference frequency from reference frequency source **30** through transformer **52** across chopper input terminals **54,56.** Chopper **50** operates in the conventional manner to convert the rate input $\phi'$ to the chopping frequency of 400 c.p.s. The output of chopper **50** from output terminals **58** and **60** is fed through coupling capacitors **62,64** into amplifier **22** which is a push-pull amplifier including a pair of NPN transistors **66** and **68.** Bias for the bases of transistors **66** and **68** is furnished through resistors **70, 72, 77** and common bleeder resistor **74.** Emitter bias is furnished by resistors **78, 84** and **82, 86** in the manner shown. Bypass capacitors **75,76** and **80** are utilized to avoid loss in gain. Capacitor **87** is connected across the collectors of transistors **66** and **68** and is used as a peaking capacitor to tune coil **88.** The output of amplifier **22** is fed into coupling transformer **88** which provides through its secondary and across resistance **90** and potentiometer **92** the rate signal corresponding to $b\ \phi'$.

The output from position pickoff **12** corresponds to the term $\phi$. Position pickoff **12** is embodied as a differential transformer whose output voltage is of the order of 1.00 volts per degree of angular movement of gyro **10** and whose output will be in phase with the excitation frequency for one direction of error input and 180° out of phase for the opposite direction of error input. The position signal is developed across potentiometer **94** and fixed resistor **96.** The rate signal through fixed resistor **98** and the position signal through resistor **96** at the primary of transformer **99** and the ratio at which these are summed is determined by the ratio of resistor **98** to resistor **96.** Potentiometers **92** and **94** are selectively adjustable as gain control devices. At the summing point at the primary of transformer **99,** the rate and position signals which will appear as 400 c.p.s. signals are added. If the two signals are in phase, they will be added to give a resultant greater than either the rate or position signal as they exist separately. If the two signals are out of phase then only the difference between their relative amplitudes will remain across the primary winding of transformer **99.** The composite rate plus position signal is coupled by transformer **99** to a push-pull amplifier stage comprising NPN transistors **100** and **102.** Biasing is accomplished by resistors **104, 106,** 108, 110, 112, and 114 as shown. Bypass capacitors 116, 118, 120 are utilized in conjunction with resistors 106, 108, and 112 as shown to maintain a constant bias. Capacitor 122 is connected across the collectors of transistors 100 and 102. The output of amplifier 20 which comprises the amplified composite rate position signal is coupled through transformer 124 to a demodulator stage 24 which includes transistors 126 and 128. A reference 400 c.p.s. signal is supplied from reference signal source 30 to the secondary of transformer 124 through a resistor network comprising resistors 130, 132 and potentiometer 134 with the amplitude of the reference signal preset by the setting of potentiometer 134. This reference signal is furnished at the required voltage-frequency for demodulation of the $a\ \phi + b\ \phi'$ signal. To provide a quiescent state current for the servo valve coil 32 and to provide power for the demodulator transistors 126, 128. The outputs of transistors 126 and 128 are connected through semiconductor diodes 136 and 138, respectively, to servo valve coil 32. The current output from the demodulator stage 24 is a D.C. with a 20 percent 400 cycle per second ripple frequencey due to the inclusion of capacitor 140. Potentiometer 142 is utilized to allow adjustment of the symmetry of current through the two servo coils 32.

FIG. 3 shows the detail of one of the servo regulator valves 42 in a closed position with its associated thrust jet 36 mounted thereon. The valve body 150 has a central hemispheric chamber portion 152 communicating with thrust jet 36 and a second chamber portion 154 formed near its righthand end. A control pressure inlet 156 is connected to the output from servo valve 34 and an operating pressure inlet port 158 is directly connected to the source of pressurized fluid 46. The valve operating member is indicated generally by the numeral 160. Operating member 160 is cylindrical in shape and differentially movable along the axis of valve body 150 in accordance with control pressure from servo valve 34. Located proximate opposite ends of operating member 160 are land portions 162 and 164 comprising driving piston 162 and damping piston 164, respectively, which are seated in central annular chambers 166 and 154 formed in valve body 150. Annular chamber 166 has a plurality of ports 168 connecting it to central chamber portion 152. Annular chamber 154 has a plurality of ports 170 communicating between operating pressure inlet 158 and chamber 154 or, alternately they may be joined through an enlarged bore through valve body 150. It will further be noted that damping piston 164 has a plurality of orifices 172, one of which is shown, longitudinally formed therein. A vent hole 174 is provided in the right end portion of valve body 150. The actual opening and closing of the valve body is accomplished by a central land portion 176 formed on operating member 160. Rightward movement of operating member 160 serves to pass operating pressure from inlet port 158 to central chamber 152 and out through thrust jet 36.

FIG. 4 shows the manifold block 40 which in connection with servo valve 34 forms the second portion of the servo system utilized in the present invention. Bolt holes 178*a–d* are provided for mounting the manifold block 40 to the base of servo valve 34 in the manner illustrated in FIG. 5, hereinafter. Aperture 178*e* communicates through manifold block 40 to servo valve 34 to provide a pressure vent therefor. The manifold block 40 has an inlet nozzle 180 and a conduit 182 formed therein serving as the input of total pressure from the source of pressurized fluid 46 to the servo valve 34. Output fittings 184 and 186 extend downwardly from the manifold block 40 and are connected through conduits to provide a control pressure for servo regulators 42 and 44, respectively. A pair of orifice fittings 188 and 190 are provided which are connected to vertically extending conduits 192 and 194 which receive the outputs of control pressure from servo valve 34. Orifice fittings 188 and 190 serve to communicate between conduits 192 and 194, respectively, and atmospheric pressure. It is the function of the manifold block 40 and servo valve 34 to rapidly generate the control pressure in linear response to an input signal, in the present embodiment as hereinbefore described, an electrical control current. The servo valve 34 utilized may be any of a number of currently, commercially available, electromagnetically operable servo valves such as those produced and sold by Weston Hydraulics Limited, a subsidiary of Borg-Warner Corporation, Van Nuys, California. The conversion of a flow rate valve to a pressure control device is achieved by providing downstream orifice fittings 188 and 190 which have a size 1.88 times the maximum valve port area provided by conduits 192 and 194. This assures sonic flow into the servo regulators 42 or 44 during the entire travel of the servo valve operating member 160. Under isothermal flow conditions the pressure in the servo regulator 42, as shown in FIG. 3, will be directly proportional to flow rate from the servo valve 34 which in turn is proportional to the valve port area as controlled by the electrical signal.

FIGS. 5 through 7 show further detail and the mode of interconnection of conduits 192 and 194 which receive the flow output from servo valve 34, the orifice fitting 188, 190 and the output fittings 184, 186. Also shown is the input fitting 180 in the manifold block 40 which communicates therethrough to provide operating pressure for the servo valve 34. The input fitting 180 is coupled directly to the source of pressurized fluid 46 in the manner illustrated in FIG. 1.

FIG. 8 shows the detail of position pickoff 12 and its cooperative relationship with the rotor 10a of gyroscope 10. Position pickoff 12 comprises a core 200 including an excitation winding 202 and a pair of output windings 204,206. An alternating current of 400 cycles per second input is applied across terminals 208, 210 to winding 202. The rotor 10*a* is shown with its iron ring 212 in juxtaposition to the respective windings on core 200. Depending on whether the pickoff 12 is above or below the reference iron ring 212, the coupling between winding 202 and windings 204, 206 will be varied. Accordingly, the amplitude of the voltage induced across the output windings 204, 206, will be varied in a manner proportional to the angle of rotation of the missile from its predetermined attitude. The phase relation of the voltages across the output windings 204, 206 will be indicative of the direction of rotation with reference to gyro rotor 10*a*. The output from leads 214, 216 is applied across resistor 94 in the manner hereinbefore indicated in FIG. 2.

FIG. 9 shows the detail of rate pickoff 14 and illustrates the manner in which it is cooperable with the reference iron ring 212 of gyro rotor 10*a* to provide a voltage output which is proportional to the rate of missile rotation from its predetermined attitude. Rate pickoff 14 is similar to pickoff 12 and includes an "E" core 300 carrying an excitation winding 302, and output windings **304** and **306** connected as shown. The input to terminals **308, 310**, however, is a direct current voltage input. A DC flux field results about the center leg of core **300**. With the rotor ring **212** centered relative to the pickoff, the flux field remains static and no voltage output occurs across output windings **304, 306**. When relative rotation occurs between the pickoff and rotor **10**a, the DC flux field is cut thereby inducing a voltage across the output windings which is proportional to the rate of rotation of the missile from its predetermined attitude. The voltage across output leads **314, 316** is of one polarity for a motion in one direction and of the opposite polarity for an opposite direction of motion. Leads **314, 316** are connected to terminals **49, 60**, respectively, as indicated in FIG. **2**.

## DESCRIPTION OF OPERATION

Upon displacement of the missile from its predetermined attitude, electrical output signals will be generated from the rotor of the gyroscope **10** through position pickoff **12** and rate pickoff **14** as signals $\phi$ and $\phi'$, respectively.

As shown in FIG. **1**, it will be seen that the multiplication of the position signal $\phi$ by the constant a and the multiplication of the rate signal $\phi'$ by the constant $b$ together with their summation is accomplished in computer **16**. With reference to FIG. **2**, the rate signal $\phi'$ is modulated to a 400 cps signal by modulator **21** and amplified i.e., multiplied by the preset factor $b$ by the push-pull amplifier stage comprising transistors **66, 68**. The position signal $\phi$ which is also a 400 c.p.s. signal is summed with $b\ \phi'$ signal across the primary of transformer **99**. Amplification of the composite rate position signal is accomplished in the push-pull amplifier stage comprising transistors **100, 102**. Demodulation operation in the final stage of computer **16** is accomplished in transistors **126, 128** operating as a class B push-pull power amplifier. Transistors **126** and **128** may be medium power silicon transistors such as type 2N497. When its base is rendered positive by the 400 c.p.s. reference signal applied across the secondary of transformer **124**, transistor **126** is in a conductive state. A current pulse at 400 c.p.s. is allowed to flow through transistor **126**, diode **136** and one-half of servo valve coil **32**. It will be noted that transistor **128** has been shut off during this period. On the next cycle of 400 c.p.s., when its base is positive, transistor **128** is turned on and transistor **126** remains off. Operation on conduction of transistor **128** provides a current flow through diode **128** and the other half of servo valve coil **32**. This alternate conduction of transistors **126, 128** results in a pulsating current flow in an opposite direction through each half of the coil. This current may be of the order of approximately 0.004 amps in each direction through the coil. Since the current flow is equal and in opposite directions, servo valve **34** will not be actuated and will remain off.

Control signals appearing at the secondary of transformer **124** will be either in or out of phase with the 400 c.p.s reference voltage frequency. The sum of the in phase components will appear across transistor **126** and the difference of the out of phase components will appear across transistor **128**. This will result in a net difference between currents through each half of coil **32**. Servo valve **34** will thus be energized in accordance with the + J or − J signals so that corrective forces proportional to those signals will be provided through jets **36** and **38**. Whether J is plus or minus will determine which of regulators **42** and **44** is activated by control pressure flow from servo valve **34**. As best shown in FIG. **3**, in the event of a negative signal, control pressure is forwarded from the servo valve **34**, through manifold block unit **40**, and through conduit **156** to the lefthand thrust face of the driving piston **162** of servo regulator valve **42**. This application of control pressure will move the cylinder valve operating member **160** rightwardly. It should be noted that operating or working pressure is at all times furnished through input conduit **158** to the servo regulator valve **42**. Prior to the rightward movement of the valve operating member **160**, operating pressure has thus been furnished through conduits **170** and apertures **172** in damping piston **164** to provide equal pressure on either thrust face of damping piston **164**. As soon as the valve operating member **160** moves rightwardly, land **176** thereon emits operating pressure to the central chamber **152**. Operating pressure is then communicated from chamber **152** with a force feedback effect through apertures **168** and into chamber **166** against the righthand thrust face of driving piston **162** to exert an opposing force to arrest rightward motion of operating member **160**. At the same time, the fluid in righthand chamber **154** is compressed and is forced readily through aperatures **170** and apertures **172** in damping piston **164**. The construction of the servo regulator **42** permits a force feedback effect against driving piston **162** and an almost simultaneous damping effect against damping piston **164**. It should be further noted that the present mode of construction eliminates the need for mechanical damping devices such as springs which might provide a nonlinearly operating valve. This elimination of mechanical damping elements makes the servo regulator valve **42** a linear pneumatic amplifier whose output is controlled by a constant balance between the input control pressure and the output pressure in chamber **152**, and is independent of the magnitude of supply pressure from pressurized fluid source **46**. The present invention has additional advantages of utilizing the high density fluid supply as a damping medium. The high density supply gas from source **46** is readily available and its employment requires the use of no special seals in piston **164** since a slight leakage of this fluid causes no problem. The damping chamber **154** formed at the righthand end of valve body **150** is made to act as a degenerative spring. Clearance for operating member **160** is provided by chamber **175** which is vented through port **174**.

It will thus be seen that I have provided a pressure regulator valve in which a control pressure from a relatively low-flow source can proportionately control the pressure of a working fluid from a relatively high flow source. The pressure regulator valve is important in the present directional control system in that it operates in a stablized manner independent of changes in fluid supply pressure.

It will thus be seen that by the present invention I have provided a directional control system and method for missiles effective to provide a constant direction of travel during its boost flight. It functions with reference to a simple inertial directional reference in an improved manner not hitherto possible.

What is claimed is:

**1**. An attitude control system for maintaining a missile on a launch predetermined path comprising means mounted on the missile for indicating a deviation from said predetermined path including means for providing an output signal representative of angular position change; and means for providing an output signal representative of angular rate change means for modifying said angular position change signal by multiplying it by a factor "*a*" whereby $a \cong [(T-D)/(k/p)-1]$ an algebraic summation means responsive to said modified position and rate change signals and operable to provide a combined output representative of their algebraic summation, and means operatively connected to and controlled by the output of said summation means, said last mentioned means operable to provide a corrective force to return the missile to its predetermined path.

**2.** An attitude control system for maintaining a missile on a launch predetermined path comprising a gyroscope having its spin axis mounted along the longitudinal axis of the missile at launch, a first and a second pickoff operatively connected to said gyroscope and responsive to movement of the spin axis of said gyroscope from said longitudinal axis, said first pickoff operable to provide an electrical output representative of position deviation and said second pickoff operable to provide an electrical output representative of rate of deviation, means for modifying the output of said first pickoff by multiplying it by a factor "*a*" whereby $a \cong [(T-D)/(k/p)-1]$ an algebraic summation means operatively connected to the modified output of said first pickoff and the output of said second pickoff for providing an electrical output signal representative of their algebraic summation, and thrust jet means mounted on said missile and lying in the same control plane as said pickoffs for providing a corrective force proportional to the output signal from said last mentioned means to return the missile to its predetermined path.

**3.** The combination as set forth in claim **2** in which an electrical servo valve has its control winding operatively connected to the output of said algebraic summation means, and a servo regulator valve is operatively connected between said servo valve and said thrust jet means and a source of constant pressure fluid to provide said corrective force.

**4.** An attitude control system for maintaining a missile in a launch predetermined path comprising means mounted on the missile for indicating a deviation from said predetermined path including a first pickoff means for providing an electrical output signal representative of angular position change and a second pickoff means for providing an electrical output signal representative of angular rate change, a means operatively connected to each of the aforesaid first and second means for multiplying each of said signals by a constant factor representative of an average value of gain coefficient as fixed by aerodynamic characteristics and geometry of the missile, means operatively connected to the output of said multiplying means for algebraically summing their outputs, and means operatively connected to and controlled by the output of said summing means, said last mentioned means operable to provide a corrective force to return the missile to its predetermined path.

**5.** The combination as set forth in claim **4** in which said last-mentioned means comprises a pair of oppositely oriented thrust jet means mounted on the missile in a common control plane with said first and second pickoff means.

**6.** The combination as set forth in claim **5** in which an electrical servo valve has its control winding operatively connected to the output of said summing means and a servo regulator is operatively connected to and controlled by said servo valve and connected between said thrust jet means and a source of constant pressure fluid to provide said corrective force.

**7.** An attitude control system for maintaining a missile on a launch predetermined path comprising a gyroscope having its spin axis fixed along the longitudinal axis of the missile at launch, a first and a second pickoff operatively connected to said gyroscope and responsive to relative movement between the spin axis of said gyroscope and said longitudinal axis, said first pickoff operable to provide an electrical output representative of position deviation and said second pickoff operable to provide an electrical output representative of rate of deviation, means for multiplying the output of each of said pickoffs by a different constant factor representative of an average value of gain coefficient as fixed by aerodynamic characteristics and geometry of the missile, an algebraic summation means operatively connected to the outputs of said multiplying means for providing an electrical output signal representative of their summation, means for applying a corrective force normal to the longitudinal axis of said missile, said last-mentioned means operable responsive to the output of said summation means to provide the corrective force in a direction normal to said longitudinal axis of said missile.

**8.** The combination as set forth in claim **7** in which said means for applying a corrective force comprises a pair of oppositely oriented thrust jets mounted on said missile, both of said jets lying in a common control plane with said first and second pickoff means.

**9.** The combination as set forth in claim **8** in which an electrical servo valve has its control winding operatively connected to the output of said summation means, and a servo regulator valve is operatively connected between said servo valve and a source of constant pressure fluid to provide said corrective force through said jets.

**10.** The method of maintaining a missile on a launch predetermined path during boost flight comprising, deriving a signal representative of the missile's deviation from said predetermined path, deriving a signal representative of the rate of the missile's deviation from said path, multiplying each of said signals by its own constant factor representative of an average value of gain coefficient as fixed by aerodynamic characteristics and geometry of the missile, algebraically summing both the resultant signals, and utilizing the composite signal to apply and control the magnitude of a corrective force to the missile.

**11.** The method of maintaining a missile on a launch predetermined path during boost flight comprising, deriving from an inertial reference a signal representative of the missile's deviation from said path, deriving from said inertial reference a signal representative of the rate of the deviation from said path, multiplying each of said signals by its own constant factor representative of an average value of gain coefficient as fixed by the aerodynamic characteristics and geometry of the missile, algebraically summing both the resultant signals, and applying a corrective jet force normal to the longitudinal axis of the missile proportional to the summed signal.

12. The method of maintaining a missile on a launch predetermined path during boost flight comprising, deriving from an inertial reference a signal representative of the missile's deviation from said predetermined path, deriving from said inertial reference a signal representative of the rate of the missile's deviation from said path, multiplying each of said signals by its own constant factor representative of an average value of gain coefficient as fixed by the aerodynamic characteristics and geometry of the missile, algebraically summing both the resultant signals, and utilizing the composite signal to apply and control the magnitude of a corrective force to the missile.

13. The method of maintaining a missile on a launch predetermined path during boost flight comprising, deriving from an inertial reference an electrical signal representative of the missile's deviation from said predetermined path, deriving from said inertial reference an electrical signal representative of the rate of the missile's deviation from said path, modulating each of said signals to a common reference frequency, multiplying each of said signals by its own constant factor representative of an average value of gain coefficient as fixed by the aerodynamic characteristics and geometry of the missile, algebraically summing both of the resultant signals, demodulating the composite signal, and utilizing the composite signal to apply and control the magnitude of a corrective force to the missile.

14. The method of maintaining a missile on a launch predetermined path during boost flight comprising, deriving a signal representative of the missile deviation from said predetermined path, deriving a signal representative of the rate of the missile deviation from said path, multiplying at least one of the aforesaid signals by a constant factor representative of an average value of gain coefficient as fixed by aerodynamic characteristics and geometry of the missile, algebraically summing the resultant signals and utilizing the composite signal to apply and control the magnitude of a corrective force to the missile.

15. The method of maintaining a missile on a launch predetermined path during boost flight comprising, deriving a signal representative of the missile deviation from said predetermined path, deriving a signal representative of the rate of the missile deviation from said path, multiplying at least one of the aforesaid signals by a constant factor "$a$" whereby $a \cong [(T-D)/(k/p)-1]$ algebraically summing the resultant signals, and utilizing the composite signal to apply and control the magnitude of a corrective force to thee missile.

16. An attitude control system for maintaining a missile in a launch predetermined path comprising means mounted on the missile for indicating its deviation from said predetermined path including a first pickoff means for providing an electrical output signal representative of angular position change and a second pickoff means for providing an electrical output signal representative of angular rate change, a means operatively connected to the output signal of one of said pickoff means for multiplying it by a constant factor "$a$" whereby $a \cong [(T-D)/(k/p)-1]$, a summing means operatively connected to the output signal of said multiplying means and the output signal of the other of said pickoff means, and means operatively connected to and controlled by the output of said summing means for providing a corrective force to return the missile to its predetermined path.

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