Aug. 16, 1955 J. F. SCHOEPPEL 2,715,709

AIRCRAFT STEERING APPARATUS

Filed Dec. 8, 1944 3 Sheets-Sheet 1

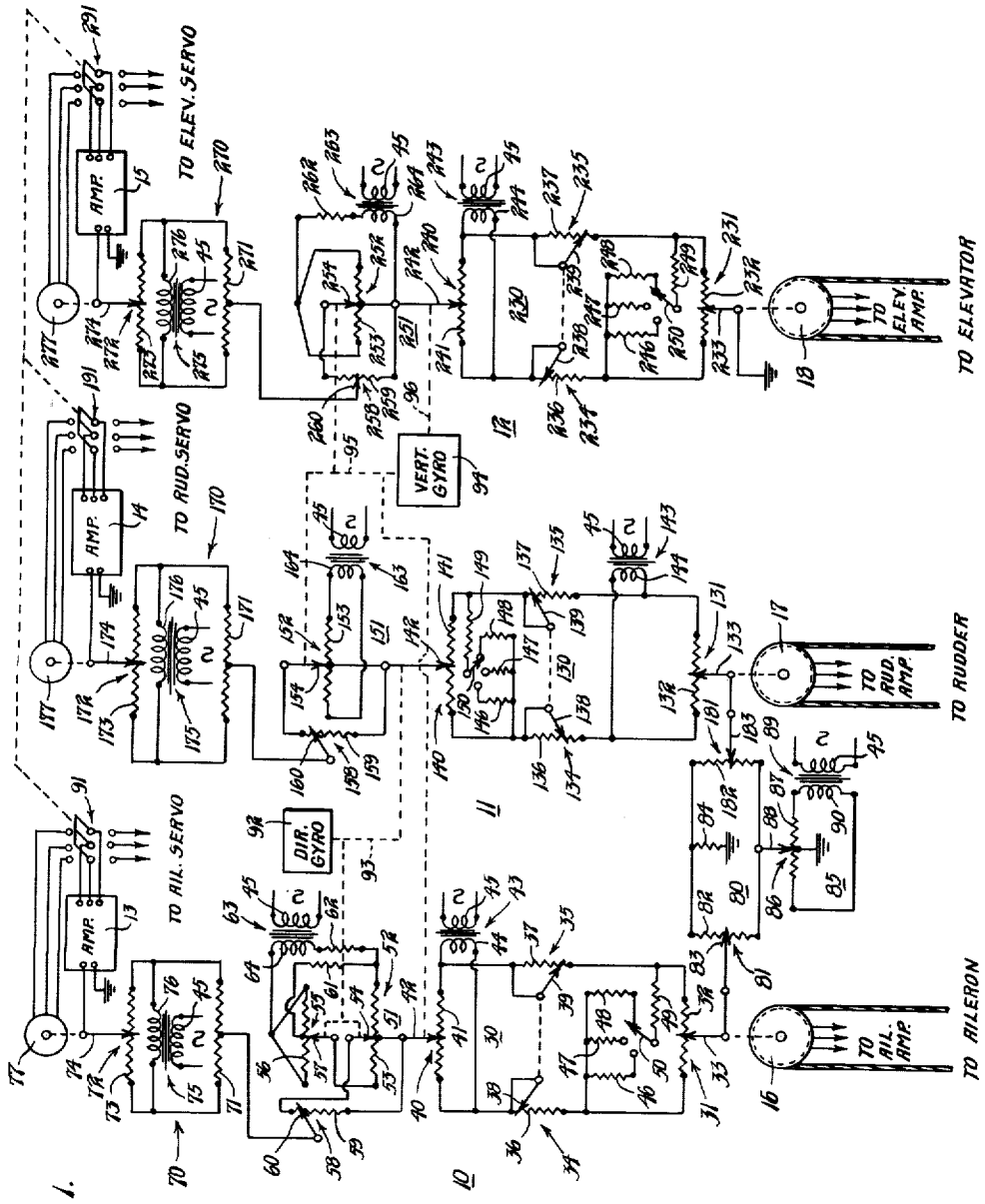


Fig. 1.

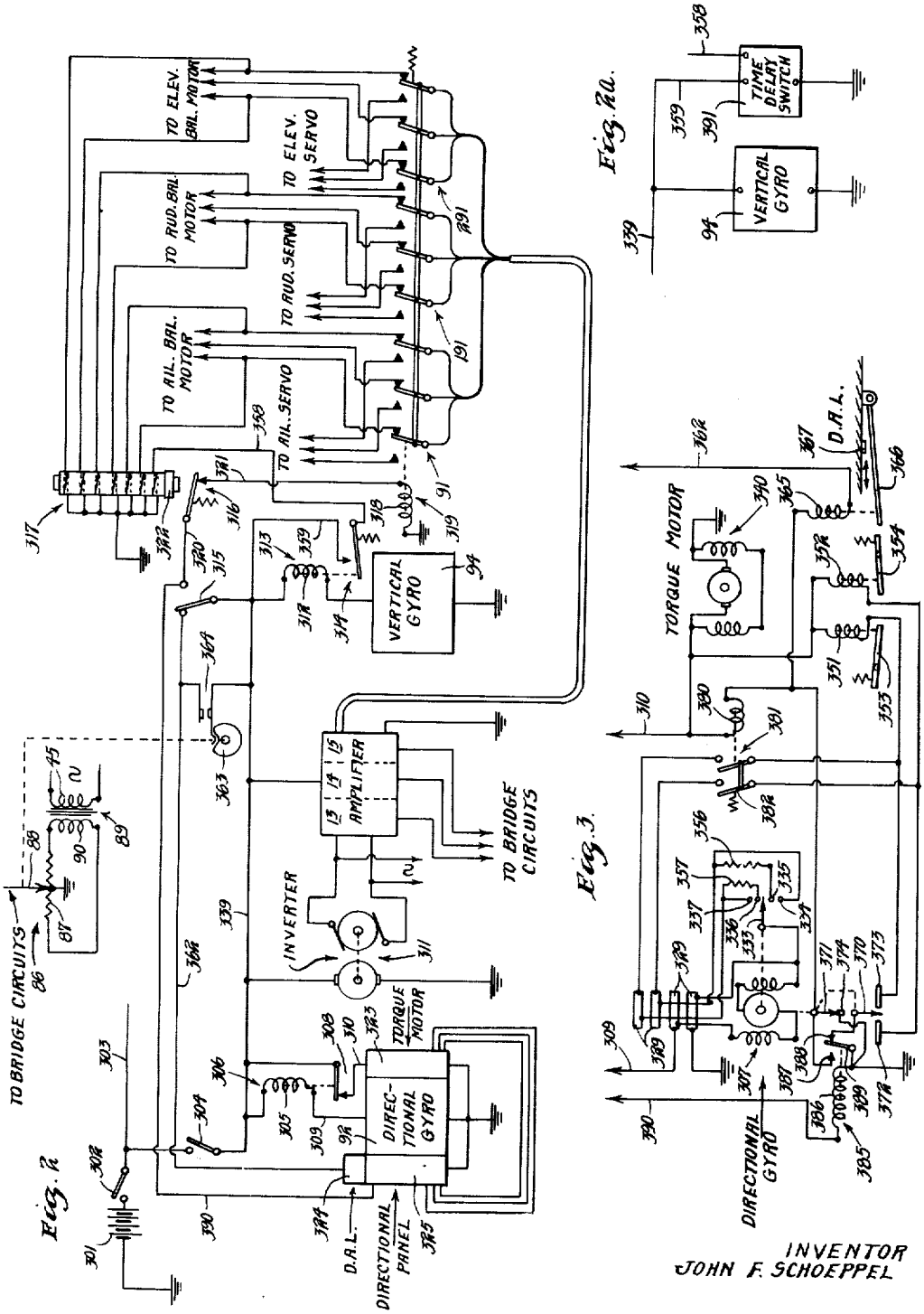
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AIRCRAFT STEERING APPARATUS

Filed Dec. 8, 1944 3 Sheets-Sheet 2



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Fig. 4.

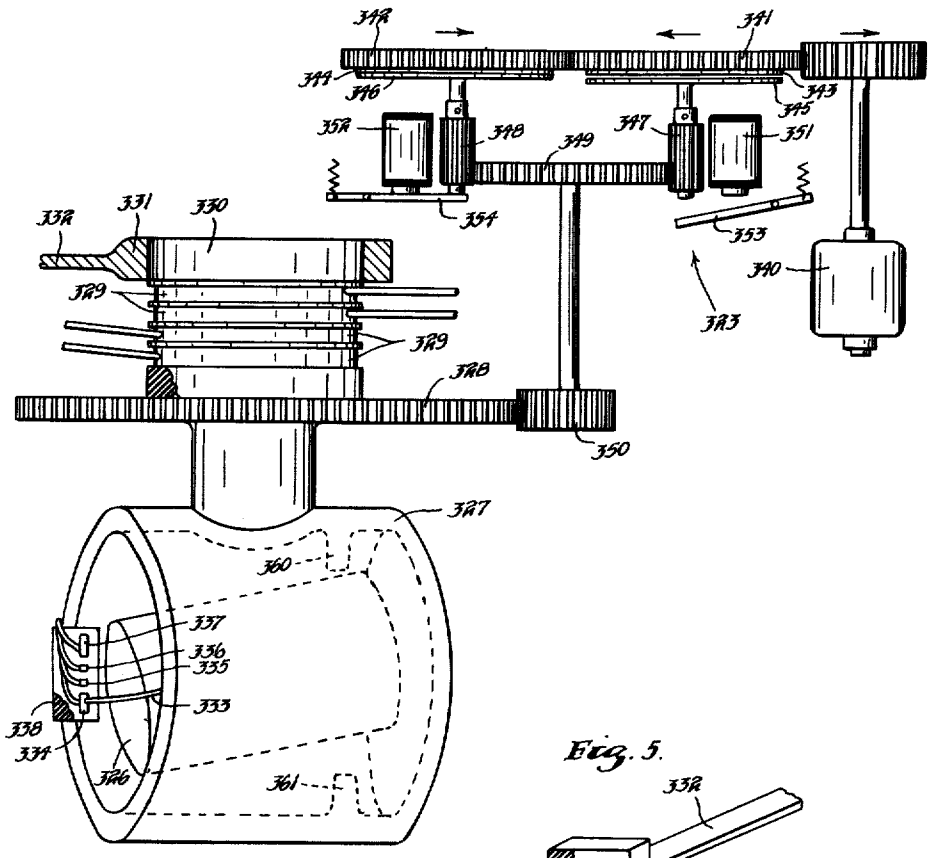
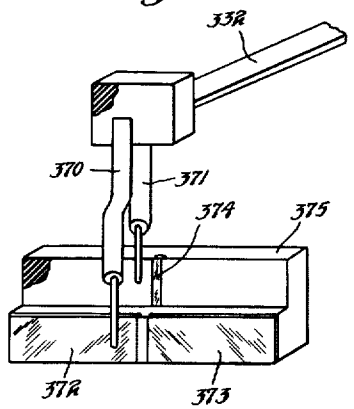


Fig. 5.



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2,715,709

AIRCRAFT STEERING APPARATUS

John F. Schoeppel, Minneapolis, Minn., assignor to Minneapolis-Honeywell Regulator Company, Minneapolis, Minn., a corporation of Delaware

Application December 8, 1944, Serial No. 567,254

50 Claims. (Cl. 318—489)

My invention relates generally to control systems and more particularly to systems having a condition responsive element and a rebalancing element connected together so that an unbalance between the two will cause the operation of a condition controlling means and simultaneously operate the rebalancing element to place the system in a new condition of balance.

In the operation of airplanes, because of the loading or other unbalance, it is often necessary to make greater use of a control surface, such as the elevator, to maintain the plane in a level attitude and on the same heading. When there is such an unbalance, if the control surfaces were in streamlined position, the plane would deviate from the desired condition; hence the control surfaces must be maintained in a different position, and any deviation of the surface from that position causes the usual reaction of the plane. This new or balanced position must be maintained all the time that the plane is in the proper attitude and on the proper heading, changes being made only when there is a deviation from these conditions; and this is true whether the plane is being flown by a human or an automatic pilot. Since the unbalance may vary in direction and magnitude, though generally remaining substantially constant for a given flight, a properly designed autopilot will have provision for aligning the balanced position of the control surfaces with the zero point, or position of no control signal, of the controlling device. The majority of autopilots use a gyroscope as the controlling device to sense any deviation of the plane from its desired attitude or heading, and to originate the proper signal to operate the control surfaces so as to return the plane to its proper attitude. Means must therefore be provided for aligning the balanced position of the control surfaces with the zero point of the gyroscope, as previously mentioned; and, depending upon whether the operating means is electrical, mechanical, or fluid, this aligning means may take the form of resistors, linkages, or valves.

Because of the versatility and precision available with electrical circuits, their use as a control means has found increasing favor among pilots. In the hands of an experienced pilot, the electrically operated automatic pilot produces results superior to those of any differently operated means, and an example of such an automatic pilot is shown in the application of Willis H. Gille, Serial No. 447,989, filed June 22, 1942. However, one of the disadvantages of an electrically operated system has been the somewhat involved procedure necessary for a proper adjustment of the automatic pilot. Because of the sensitivity and fast response of the electrical system it is necessary that the aligning, or centering, be accomplished accurately; and it has been found that many pilots, through inexperience or inattention, fail to align the electrical system with the physical trim of the airplane, and hence when the autopilot is engaged there is a pronounced lurch as the ship assumes a new position.

It is therefore a major object of my invention to provide a control system which requires less attention and ability on the part of the operator than systems previously used, but one which nevertheless will provide a degree and quality of control previously attainable only by skilled operators.

It is another object of my invention to provide a control system wherein operations which previously had to be performed sequentially and after proper time delay, are performed automatically without further attention from the operator.

It is also an object of my invention to provide a control system having automatic centering or balancing means adapted to balance the system when the apparatus controlled by it is not connected thereto.

It is an object of my invention to provide a control system which may not be operated if a malfunction exists or if certain required conditions have not been met.

It is a further object of my invention to provide a gyroscope having control elements connected thereto and means associated therewith to center these elements automatically when the gyroscope reaches a predetermined speed.

It is an object of my invention to provide a gyroscope having motor means to maintain the rotor of the gyroscope normally in a horizontal position, and having means preventing operation of the motor until the gyroscope rotor has reached a predetermined speed.

It is another object of my invention to provide a gyroscope which may not be connected into a control system if its rotor has not reached a predetermined speed.

Still another object of my invention is to provide a balancing means which may be connected so as to furnish a signal opposing the signal from a control system, thereby providing a resulting signal which is zero or which differs from zero by a predetermined amount.

These and other objects of my invention will become apparent from the following description of a preferred form thereof and the drawings illustrating that form, in which

Figure 1 is a schematic diagram of the alternating current networks used in my system,

Figure 2 is a schematic diagram of the power and interlock circuit used in my system,

Figure 2*a* is a schematic diagram of a portion of the power diagram shown in Figure 2, and showing a modified embodiment of my invention,

Figure 3 is a detailed schematic diagram of the directional stabilizer and parts associated therewith,

Figure 4 is a view of the gyroscope of the directional stabilizer showing the action of the torque motor and

Figure 5 is a detailed view of the centering contacts used in conjunction with the directional stabilizer.

Referring now to the drawings and particularly to Figure 1 thereof, the numeral **10** indicates a network of several bridges containing condition responsive devices so arranged that a change in condition, sensed by them, will be sent as a signal to an amplifier **13** where the signal will be amplified and used to operate a servo motor **16** connected by cables to the ailerons, not shown, of the airplane. A similar network **11** connected to amplifier **14** operates servo motor **17** to control the rudder, not shown, while an elevator network **12** sends a signal to an amplifier **15** which controls a servo motor **18** driving the elevator, not shown.

In the aileron network **10** a bridge **30** has a rebalancing potentiometer **31** consisting of a resistor **32** and a wiper **33**, a pair of centering potentiometers **34** and **35** consisting of resistors **36** and **37** with wipers **38** and **39**, respectively, a gyroscopically controlled potentiometer **40** consisting of a resistor **41** and a wiper **42**, a source of power such as a transformer **43** having a secondary wind-

ing 44 and a primary winding 45 and a series of fixed resistors 46, 47, 48 and 49. The gyroscope resistor 41 is connected across the secondary 44; and the rebalancing resistor 32 in series with resistors 36 and 37 of centering potentiometers 34 and 35 is connected in parallel with the gyroscope resistor 41. The upper end of centering resistor 36 is connected to its wiper 38 so that as the latter is moved back and forth more or less of the resistor 36 is shorted. A similar connection is made between centering resistor 37 and its wiper 39 and the two wipers are mechanically connected together and provided with manually controllable means so that as one of the two resistors has progressively more of its resistance shorted, the other resistor has progressively less of its resistance shorted. In this way the total resistance through potentiometers 31, 34, and 35 remains a constant as the centering potentiometer wipers 38 and 39 are moved from one extreme position to the other. A shunt connection across rebalancing potentiometer 31 is provided by resistance 49 which is selectively connected in series with one of three fixed resistors 46, 47, or 48 by switch 50. The resistors 46, 47 and 48 have different values and are arranged so that a high, medium, or low resistance shunt across balancing potentiometer 31 may be provided.

Above bridge 30 in network 10, as shown in Figure 1, is a second bridge 51 consisting of a banking potentiometer 52 having a center tapped resistor 53 and a wiper 54, an accelerating potentiometer 55 having a center tapped resistor 56 and wiper 57, a compensating potentiometer 58 having a resistor 59 and a wiper 60, a pair of resistors 61 and 62, and a source of power, shown as a transformer 63 having a secondary winding 64 and primary winding 45. The ends of the accelerating resistor 56 are connected together and to one terminal of the secondary 64 of the transformer 63 and the center tap is connected through resistor 61 and resistor 62 to the other terminal of the secondary 64. The wiper 57 of the accelerating potentiometer 55 is connected to one end of the resistor 53 of the banking potentiometer 52 and the other end of the resistor 53 is connected through resistor 62 to its terminal of the secondary 64 of the transformer 63. The center tap of resistor 53 is connected to the wiper 42 of gyroscope potentiometer 40 and is also connected to one end of resistor 59 of compensating potentiometer 58 while the wiper 54 of banking potentiometer 52 is connected to the opposite end of the resistor 59. It will thus be seen that the voltage impressed across the resistor 53 of the banking potentiometer 52 will be dependent upon the position of the wiper 57 of the accelerating potentiometer 55, this voltage being a minimum when the wiper is aligned with the center tap of the potentiometer 55 and a maximum when it is at either extreme position to one side. Since the ends of the resistor 56 of the accelerating potentiometer 55 are connected together there will be no inversion or shifting of phase as the wiper 57 passes from one side of the center tap to the other; whereas in potentiometer 52, as wiper 54 moves from one end of resistance 53 to the other, the voltage measured between the center tap and the wiper 54 will decrease until a zero value is reached when the wiper is in line with the center tap and then gradually increase, but with a phase shift of 180 degrees, reaching a maximum when the wiper 54 is at the other extreme end of resistor 53. Wiper 57 of accelerating potentiometer 55 and wiper 54 of banking potentiometer 52 are mechanically connected together so that both move simultaneously in the same direction as they leave their center positions so that a higher voltage is impressed across resistor 53 and a greater percentage of this total voltage across this resistor appears between the center tap and wiper 54. This voltage will thus vary as something more than a linear function of the displacement and, because of resistances 61 and 62, will be somewhat less than a squared or second order function, but

will nevertheless be an exponential function lying somewhere in between these two limits.

From wiper 60 connection is made to a bridge 70 which includes a center tapped resistor 71, a balancing potentiometer 72 consisting of a resistor 73 with a wiper 74, a source of power such as a transformer 75 having a secondary winding 76 and a primary winding 45. The center tapped resistance 71 is connected across the secondary winding 76 of the transformer 75 while the center tap of the resistor is connected to the wiper 60 of the compensating potentiometer 58; the potentiometer 72 is likewise connected across the secondary winding 76 so that the resistors 71 and 73 are in parallel and the voltage signals developed by the bridge 70 will appear across the center tap of the resistor 71 and the wiper 74 of the potentiometer 72. From wiper 74 connection is made to the amplifier 13, which, under certain conditions, drives a balancing motor 77 to which the wiper 74 is mechanically connected.

The rudder network 11 is similar in many respects to the aileron network 10 and consists of three bridges 130, 151, and 170 connected together similarly to bridges 30, 51 and 70. Bridge 130 includes a rebalancing potentiometer 131 having a resistor 132 and a wiper 133, a pair of centering potentiometers 134 and 135 consisting of resistors 136 and 137 with wipers 138 and 139, respectively, a gyroscopically operated potentiometer 140 consisting of resistor 141 and wiper 142, a three-position switch 150, and fixed resistors 146, 147, 148 and 149.

The rebalancing potentiometer 131 is connected across the output terminals of the secondary 144 of a transformer 143, and a series circuit, consisting of the centering potentiometer 134, the gyroscopically operated potentiometer 140 and the centering potentiometer 135, is connected in parallel with the balancing potentiometer 132. The wiper 138 is electrically connected to one end of the centering potentiometer 134 and the wiper 139 is similarly connected to one end of the potentiometer 135 so that movement of the wiper shorts a greater or lesser amount of its associated resistance. The two wipers are mechanically connected together and provided with manual operating means so that as the wipers are moved, the total resistance in the series circuit consisting of the centering potentiometer 134, the gyroscopically operated potentiometer 140, and the centering potentiometer 135, remains a constant. Connected in parallel with the gyroscopically operated potentiometer 140 is a resistance circuit consisting of fixed resistor 149 connected through switch 150 to one of the three fixed resistors 146, 147, or 148, these last three resistors having different values so that depending upon the position of switch 150, a low, medium, or high resistance circuit is shunted across the potentiometer 140.

From wiper 142 of the gyroscopically operated potentiometer 140 connection is made to a bridge 151 which includes a gyroscopically operated "skid" potentiometer 152 having a center tapped resistor 153 and a wiper 154, a compensating potentiometer 158 which has a resistor 159 and a wiper 160, and a source of power such as a transformer 163 having a secondary winding 164 and a primary winding 45. The ends of the resistor 153 are connected to the leads from the secondary 164 of the transformer 163, and the center tap of the resistance is connected to the wiper 142 of the gyroscopically operated potentiometer 140. Wiper 154 of the "skid" potentiometer 152 is connected to one end of the resistor 159 of the compensating potentiometer 158, while the other end of the resistor is connected to the center tap of the resistor 153 so that wiper 160 of the compensating potentiometer 158 may be set to receive any desired percentage of the voltage developed between the center tap and the wiper 154 of the potentiometer 152.

Bridge 170 is similar in all respects to bridge 70 shown in the aileron network and has a center tapped resistor 171, a balancing potentiometer 172 consisting of a re-

sistor 173 and a wiper 174, and a transformer 175 having a secondary 176 and a primary 45. Center tapped resistor 171 is connected across the output terminals of the secondary 176 of the transformer 175 and the resistor 173 of the centering potentiometer 172 is likewise connected across the output terminals of the secondary 176 placing it in parallel with center tapped resistance 171. The center tap of resistor 171 is connected to wiper 160 of the compensating potentiometer 158, and wiper 174 of balancing potentiometer 172 is connected to the input of an amplifier 14 which, under certain conditions, will drive a balancing motor 177 which positions the wiper 174.

The aileron and rudder networks are connected together through a bridge 80 consisting of an aileron trimming potentiometer 81 having a resistor 82 and a wiper 83, a rudder trimming potentiometer 181 having a resistor 182 and a wiper 183, and a fixed resistor 84. Wiper 83 of aileron trimming potentiometer 81 is connected to wiper 33 of the rebalancing potentiometer 31; wiper 183 of the rudder trimming potentiometer 181 is connected to the wiper 133 of the balancing potentiometer 131; and the resistors 82 and 182 of potentiometers 81 and 181 are connected together so that they are in parallel. The parallel circuit thus formed is grounded through fixed resistor 84, while the other side of the parallel circuit is connected to a bridge 85 consisting of a potentiometer 86 having a center tapped resistor 87 with wiper 88, and a source of power such as a transformer 89 having a secondary winding 90 and a primary winding 45. The resistor 87 is connected across the terminals of the secondary 90 of transformer 89, the center tap of the resistor is grounded, and the wiper 88 is connected to the bridge circuit 80 as previously mentioned. Since one of the input terminals of each of the amplifiers 13 and 14 is grounded, a completed circuit may readily be traced from the grounded center tap of potentiometer 86 through bridge 80 to wiper 33 of rebalancing potentiometer 31, through the centering potentiometers 34 and 35, and through gyroscopically operated potentiometer 40 to bridge 51, where it goes through the compensating potentiometer 58, picking up any signal from banking potentiometer 52, and then to bridge 70, going through center tapped resistance 71 and potentiometer 72 and the wiper 74 thereof to one terminal of the amplifier 13 and thence to ground. Similarly, a circuit may be traced through the rudder network 11 and amplifier 14.

The elevator network 12 is generally similar to the aileron network 10 and rudder network 11 and consists of three bridges 230, 251 and 270 connected in series and to the elevator amplifier 15.

Bridge 230 includes a rebalancing potentiometer 231 having a resistor 232 and a wiper 233, a pair of centering potentiometers 234 and 235 having resistors 236 and 237 with wipers 238 and 239 respectively, a gyroscopically operated potentiometer 240 having a resistor 241 and a wiper 242, a source of power such as a transformer 243 having a secondary winding 244 and a primary winding 45, fixed resistors 246, 247, 248, 249, and a three position switch 250. The gyroscopically operated potentiometer 240 is connected across the terminals of a secondary 244 of the transformer 243, and a series circuit consisting of the centering potentiometer 234, the rebalancing potentiometer 231 and the centering potentiometer 235 is likewise connected across the terminals so that this series circuit is in parallel with the potentiometer 240. One end of the resistor 236 of the centering potentiometer 234 is connected to its associated wiper so that movement of the wiper will shunt a greater or lesser portion of the resistor 236. One end of resistor 237 of potentiometer 235 is likewise electrically connected to its wiper 239 and wipers 238 and 239 are mechanically connected together so that as a greater portion of one resistor is shunted, a lesser portion of the other one is shunted and the total resistance through the

circuit consisting of potentiometer 234, rebalancing potentiometer 231 and centering potentiometer 235 remains a constant as these wipers are moved. A resistance branch consisting of the fixed resistor 249 and fixed resistor 246, 247 or 248 is connected in parallel with balancing potentiometer 231 and the resistance values of these fixed resistors is so chosen that they will form low, medium and high resistance paths in parallel with the centering potentiometer 231. The resistance value desired may be selected by the three position switch 250, and I prefer to connect the three-position switches in each of the three axes so that switches 50, 150 and 250 may be simultaneously operated from a single lever.

Wiper 233 of rebalancing potentiometer 231 is grounded, and wiper 242 of the gyroscopically operated potentiometer 240 is connected to bridge 251 which includes an "up-elevator" potentiometer 252 having a center tapped resistor 253 and a wiper 254, a compensating potentiometer 258 having a resistor 259 and a wiper 260, a fixed resistor 262 and a source of power such as a transformer 263 having a secondary winding 264 and a primary winding 45. The "up-elevator" potentiometer 252 has the ends of its resistor 253 connected together and through resistor 262 to one terminal of the secondary 264 of the transformer 263. The center tap of the potentiometer 252 is connected to the other terminal of the secondary 264 and also to one end of the resistor 259 of the compensating potentiometer 258. Wiper 254 of the "up-elevator" potentiometer 252 is connected to the other end of resistor 259 of the compensating potentiometer 258, and since the ends of resistor 253 of the "up-elevator" potentiometer 252 are connected together, it will be seen that there will be no phase shift in the voltage appearing across the compensating potentiometer 258 as wiper 254 is moved from one side of the center tap to the other. Wiper 242 of the gyroscopically operated potentiometer 240 is also connected to the center tap of potentiometer 252, and by varying the position of wiper 260 of the compensating potentiometer 258 any desired percentage of the voltage appearing across the ends of the latter potentiometer may be selected and carried on to the centering bridge 270.

Centering bridge 270 is similar to the centering bridges 70 and 170 of the aileron and rudder networks and includes a center tapped resistor 271, a centering potentiometer 272 having a resistor 273 and a wiper 274, and a source of power such as a transformer 275 having a secondary 276 and a primary winding 45. The center tapped resistor 271 is connected across the output terminals of the secondary 276 of the transformer 275 and the resistor 273 of the centering potentiometer 272 is likewise connected across these terminals so that resistor 273 and resistor 271 are connected in parallel. Wiper 260 of the compensating potentiometer 258 is connected to the center tap of resistor 271 and the wiper 274 of the centering potentiometer 272 is connected to one of the input terminals of the amplifier 15, which under certain conditions, is used to drive balancing motor 277 which mechanically moves wiper 274 of the balancing potentiometer 272.

One of the input terminals of amplifier 15 is grounded and it is thus possible to trace a circuit from the grounded wiper 233 of rebalancing potentiometer 231 through centering potentiometers 234 and 235, through the gyroscopically operated potentiometer 240 and the wiper 242 thereof to the bridge 251, where it continues through potentiometer 252 and its wiper 254 and compensating potentiometer 258, going from wiper 260 thereof to center tapped resistance 271 and centering resistance 272, from which it travels through wiper 274 to the amplifier 15 and then to ground.

To transfer control of the amplifiers 13, 14, and 15 from the balancing motors 77, 177, and 277 which position centering potentiometer wipers 74, 174 and 274, respectively, to the servomotors 16, 17 and 18 operating the aileron, rudder, and elevator surfaces respectively,

switching means **91**, **191** and **291** are provided in the output circuits of amplifiers **13**, **14** and **15**.

It will be noted that I have shown all transformers connected to the networks **10**, **11**, and **12** as having a common primary **45**. It will be readily apparent that a single transformer having a plurality of secondary windings, or a number of individual transformers, or any combination of the two may be used.

The details of the amplifiers **13**, **14** and **15** and servomotors **16**, **17** and **18** form no part of my invention, since such amplifiers and servomotors are well known in the art and may be any of a suitable type, such as that shown in the patent to Anschutz-Kaempfe No. 1,586,233 or Whitman No. 1,942,587. Likewise, I do not claim that part of networks **10**, **11**, and **12** consisting of bridges **30**, **51**, **130**, **151**, **230**, and **251** in and of themselves, since such networks are known and have not been developed by me.

In the system shown herein, the wipers **33**, **133** and **233** of the balancing potentiometers **31**, **131** and **231** are operated by the servomotors **16**, **17** and **18** respectively. The wipers **38**, and **39**; **138** and **139**; and **238** and **239** of the centering potentiometers **34** and **35**; **134** and **135**; **234** and **235** respectively are manually operable; wipers **60**, **160** and **260** of compensating potentiometers **58**, **158** and **258** are likewise manually operable, wipers **74**, **174** and **274** of balancing potentiometers **72**, **172** and **272** are operated by balancing motors **77**, **177** and **277**; wiper **88** of potentiometer **86** is manually controlled and wipers **83**, and **183** of trimming potentiometers **81**, and **181** may likewise be adjusted by hand.

A directional gyroscope **92**, more fully described hereinafter, provides a reference for any deviation of the plane in azimuth, and a mechanical linkage **93** operates the wiper **54** of the banking potentiometer **52** and simultaneously operates the wiper **57** of the banking acceleration potentiometer **55** whenever there is a deviation from a predetermined heading. The linkage **93** also operates the wiper **142** of the rudder gyroscopically operated potentiometer **140** so that a total of three wipers **54**, **57**, and **142** are simultaneously operated by the directional gyroscope. A vertical gyroscope **94** is provided with mechanical means **95** which measures any deviation of the plane about a roll axis, i. e., about an axis extending lengthwise of the plane, and this mechanical means **95** simultaneously operates the wiper **42** of the aileron gyroscopically operated potentiometer **40**, the wiper **154** of the "skid" potentiometer **152**, and wiper **254** of the "up-elevator" potentiometer **252**. Another mechanical means **96** is operated by the vertical gyroscope **94** to indicate any deviation of the plane in pitch axis, i. e., about an axis extending crosswise of a ship, and the means **96** operates the wiper **242** of the gyroscopically operated potentiometer **240** in the elevator circuit.

Operation of bridge circuits

Neglecting for the present the method of engaging the control system, if it is assumed that the airplane is now under the control of the system shown herein with the switching means **91**, **191** and **291** connected so that the amplifier controls the operation of the servomotors **16**, **17** and **18**, it will be seen that if there are no disturbing influences and the plane is to remain in the same attitude and on a predetermined heading, there must be no movement of the control surfaces operated by the servomotors **16**, **17** and **18**; and the construction of the servomotors and the amplifiers **13**, **14** and **15** which are used is such that under these conditions there must be no signals from the aileron, rudder and elevator networks **10**, **11** and **12**, respectively, to their respective amplifiers. If, through some external cause, the plane now deviates in azimuth, this change in heading will be sensed immediately by the directional gyroscope **92** which will cause the linkage **93** to operate the wipers **54** and **57** of the potentiometers **52** and **55** in the aileron network and also wiper **142** of the gyroscopically operated potentiometer **140** in the rudder network. This will cause a voltage signal to be developed across the ends of the compensating potentiometer **58**, and the wiper **60** thereof will send a portion of this signal to the bridge **70** and thence to the amplifier **13** which in turn operates the aileron servomotor **16** so as to bank the plane toward its original course, as will be described in more detail later. Simultaneously, the wiper **142** of the gyroscopically operated potentiometer **140** in the rudder network is moved from its original position, and by the principle of the well known Wheatstone bridge, this will cause a voltage signal to be developed between the wiper **133** of the rebalancing potentiometer **131** and the wiper **142**, which will be transmitted through bridges **151** and **170** to the amplifier **14** which drives the servomotor **17** in a direction to cause the rudder to turn the ship toward its original heading.

Following now the various steps which occur as the servomotor **17** drives the rudder to a position to return the ship to its original heading, the servomotor also operates the wiper **133** of the rebalancing potentiometer **131** so that as the wiper is moved, the signal developed across bridge **130** decreases as the rudder reaches its extreme position. However, the movement of the rudder has started the turning of the ship toward its original heading, and this correction has been sensed by the directional gyroscope **92** which thereupon starts to return the wiper **142** of the gyroscopically operated potentiometer **140** to its original position. This will eventually cause the signal across the bridge **130** to decrease to zero value and then increase, but with a 180 degrees phase shift from the original signal. This phase shift is detected by the amplifier **14** and the latter thereupon reverses the direction of rotation of the servomotor **17** so that the rudder is gradually returned toward its neutral position.

A similar action has been taking place in the aileron network **10** save that in that network the signal has been developed by the bridge **51**, and transmitted to the amplifier **13** which drives the servomotor **16**, and the latter operates the wiper **33** of the rebalancing potentiometer **31** so that a signal appears across the bridge **30** which tends to oppose that appearing across the bridge **51**. It will be remembered that the potentiometers **52** and **55** in the bridge **51** cooperate to provide an exponential signal, i. e., a signal whose voltage varies exponentially as a function of the displacement of the wipers from center and hence it will be seen that for small deviations in azimuth only a small amount of aileron correction is applied whereas for large deviations in azimuth a disproportionately greater amount of aileron control is provided. It has been found that a system which provides this exponential feature produces the most accurate flying, since with small deviations, the plane is "skidded" into proper position, while with larger deviations, coordinated recoveries are made.

The vertical gyroscope **94** may be of any suitable type of which there are several known in the art, and its action, as previously described, is to sense any change in the attitude of the ship about its roll or pitch axes. As the plane tilts or banks about its roll axis, the vertical gyroscope **94** remains in its vertical position while the plane moves about it, and wiper **42** of the gyroscopically operated potentiometer **40**, wiper **154** of the "skid" potentiometer **152**, and wiper **254** of the "up-elevator" potentiometer **252** will thus be moved across their respective potentiometers which are rigidly mounted with respect to the frame of the airplane. The movement of wiper **42** with respect to resistor **41** of the aileron gyroscopically operated potentiometer **40** will unbalance the bridge **30** and cause a signal to be sent to the amplifier **13** which will in turn operate the servomotor **16** to return the ship to its original position in much the same manner as has been previously discussed except that no exponential signal is introduced in the aileron network **10**. At the same time wiper **154** is moved with respect to resistance **153** of the "skid" potentiometer **152** to cause the signal

to be sent to the amplifier **14** to operate servomotor **17** and provide rudder action to assist in returning the ship to its previous position. The need for both aileron and rudder action to restore the plane to its original position will be apparent when it is remembered that when one wing of the plane is lower than the other, the plane tends to turn toward the lower wing; and to overcome this tendency, rudder control is needed to maintain the craft on its same heading while at the same time aileron control is applied to bring the wings back to their level position. Similarly, aileron control is applied when the ship is making a turn as controlled from the directional gyroscope since the ailerons aid considerably in turning a plane; in fact, in some of the larger planes the ship may be turned by using only the aileron and disregarding the rudder control.

To provide means for adjusting the rate of return from a given angular deviation of the heading of the plane, the compensating potentiometer **58** may be adjusted to select the desired amount of bank, upon which the rate of return will depend. For the most efficient flying and for the greatest comfort of the passengers, all turns and bank should be coordinated. That is, the resultant of the centrifugal force in the turn and the acceleration due to gravity should be parallel to the normal vertical axis of the plane, and there will thus be no sensation of skidding (which occurs when the plane is insufficiently banked and objects are urged outwardly from the center of the turn) nor any sensation of slipping (when the plane is too steeply banked and objects are urged toward the center of the turn). Since the banking potentiometer **152** is operated by the vertical gyroscope **94** whenever the plane is banked, the wiper **160** of the compensating potentiometer **158** may be adjusted to give the needed amount of rudder action so that the operation of the plane will be coordinated and there will be no skidding or slipping when the plane is in a bank.

As is well known to those who have piloted an airplane, whenever the plane is banked, a certain amount of lift is lost and the plane thus tends to settle or lose altitude even though it may retain the same attitude as measured about its pitch axis. When a plane is operated manually, the pilot applies up-elevator whenever he is in a bank either to the right or left to overcome this tendency; and the same effect is obtained in this control system by the mechanical means **95** moving the wiper **254** of the "up-elevator" potentiometer **252** away from its center position whenever the plane is banked to either side.

As has been previously mentioned, the movement of the wiper **254** toward either side of the potentiometer **252** introduces a signal into the network **12** which varies as the distance of the wiper from the center, but which has the same phasing on either side of the center tap of the potentiometer. The signal resulting from this movement of the wiper **254** of the up-elevator potentiometer **252** is phased so as to cause the amplifier **15** to operate the servo motor to drive the elevator in an upward direction, and by adjusting the wiper **260** of the compensating potentiometer **258** a sufficient amount of up-elevator may be obtained to maintain the craft at the same altitude while it remains in the bank.

The vertical gyroscope **94** also operates to maintain the craft in its same attitude about its pitch axis so that it does not nose up or down and thus climb or dive. This is done by the mechanical means **96** which detects any variation about the pitch axis of the plane and moves the wiper **242** of the gyroscopically operated potentiometer **240** so that the bridge **230** then develops a signal which is transmitted to the amplifier **15** to control the elevator servo motor **18** and apply the necessary corrective movement to the elevator itself. The operation of the servo motor **18** drives the wiper **233** of the rebalancing potentiometer **231** and the sequence of operation is then similar to that described in the operation of the rudder network previously covered. It should be noted that the up-elevator potentiometer **252** is connected so that any movement of its wiper **254** from its center position will cause the servomotor **18** to drive the elevator upwardly whereas movement of the wiper **242** of the gyroscopically operated potentiometer **240** will cause the elevator to be driven upwardly when moved to one side of center and downwardly when moved to the other side of center.

When the plane is flying under the control of this system and it is noted that because of shifting load, different amounts of power in the engine of either wing, or for any other reason the plane is not in the desired attitude, the centering potentiometers **34** and **35**; **134** and **135**; **234** and **235** may be used to change the position of the ailerons, rudder, or elevator respectively. To understand the operation of this, let it be assumed that he bridge **30** of the aileron network **10** is balanced so that it develops no voltage between the wiper **33** of the rebalancing potentiometer **31** and the wiper **42** of the gyroscopically operated potentiometer **40**, and that wipers **33** and **42** are in their mid-positions as are wipers **38** and **39** of the centering potentiometers **34** and **35**. If the wipers **38** and **39** of the centering potentiometers **34** and **35** are now moved to the position shown in Figure 1, resistance will have been added to the left hand side of the bridge and removed from the right hand side of the bridge creating an unbalance and causing the amplifier **13** to drive the servomotor **16** so as to move the wiper **33** of the balancing potentiometer **31** toward the left, until a new balance point is reached. The ailerons, of course, have been moved by the operation of the servomotor **16** and the airplane hence moves about its roll axis until a new point of balance for the control system is established.

As is well known to those familiar with the operation of airplanes, at low air speeds it is necessary to secure a much greater movement of the control surfaces to produce a given maneuver than it is at high air speeds; and since to have a control system which will be satisfactory, it must operate the airplane properly at low, medium and high speeds, provision has been made for varying the amount of control surface displacement for a given deviation of the plane from its predetermined position. As shown in the aileron network **10**, I have provided a three-position switch **50** which permits any one of the three fixed resistors **46**, **47** or **48** to be connected in series with fixed resistor **49** and in parallel with the balancing potentiometer **31**. Applying the laws of elementary electricity, the resistance across the parallel circuit thus formed will be the lowest when the low resistance fixed resistor is in the circuit and highest when the highest resistance fixed resistor is in the circuit; and since the combined resistance of the centering potentiometers **34** and **35** remain a constant, the total resistance across the series parallel circuit including the centering potentiometers **34** and **35**, rebalancing potentiometer **31**, and fixed resistors **46**, **47**, **48** and **49** will vary as switch **50** is thrown to its different positions. Since the voltage supplied by the secondary **44** of the transformer **43** remains substantially a constant, and since the voltage drop across the individual resistors in a series circuit varies as their resistance, it follows that when a low resistance fixed resistor is connected in series with the fixed resistor **49**, the potential difference across the ends of the resistance **32** of the rebalancing potentiometer **31** will be lower; and when a high resistance fixed resistor is connected in series with the fixed resistor **49**, the voltage drop across the resistor **32** will be higher.

It is apparent that the control system described herein operates on a system of balanced voltages, and if a given signal is put into the amplifier, the servomotor will be driven until a corresponding voltage of opposite phase is introduced by the rebalancing potentiometer **31**. If the voltage drop across the potentiometer **31** is small, corresponding to a condition when the switch **50**

is connected to a low resistance fixed resistor, the wiper 33 must be moved a greater distance to equal the given voltage signal than when the voltage drop across the potentiometer is high. Thus, when a large movement of the aileron control surfaces is desired, corresponding to a low airspeed, the switch 50 is connected to a fixed resistor having a low resistance value, and when small movement of the control surfaces is desired, corresponding to a higher airspeed, the switch 50 is connected to a resistor having a high resistance. A similar method of providing means for adjusting the degree of control surface movement is provided in the elevator bridge 230 and a comparable method based on the same general theory is provided in the rudder bridge 130 .

If it is now assumed that the plane is flying under the control of this system, maintaining the proper heading, altitude and attitude and correcting for any deviation therefrom, the pilot may still desire to turn the ship to a new heading; and to do this he could use the centering potentiometers 34 and 35 in the aileron circuit to provide the proper amount of bank and then use the centering potentiometers 134 and 135 to secure the proper amount of rudder control to provide a coordinated turn. However, this is not a very satisfactory method of making turns and hence the turn control bridge 85 is provided. To make a turn the pilot merely moves the wiper 88 of the potentiometer 86 to one side or the other, depending upon the desired direction of turn, and a voltage will be developed between the wiper 88 and the grounded center tap connection of the resistance 87. This voltage is then applied to one side of the bridge 80 which has the other side grounded through a fixed resistor 84, and by adjusting the position of the wiper 83 of the trimmer potentiometer 81 the turn control bridge may be calibrated to provide the desired bank for a given amount of movement of the wiper 88. Similarly, the amount of rudder control necessary to provide a coordinated turn for this amount of bank may be secured by adjusting the wiper 183 of the trimmer potentiometer 181; and hence by turning a single turn control potentiometer 86, the proper signal in the proper amount may be introduced in both the aileron and rudder networks to provide a coordinated turn.

It will be seen that if no other means were provided, as soon as the turn was made with the turn control potentiometer 86 the ship would change its heading and the directional gyroscope would sense this and provide a correcting signal to bring the ship back to course. To take care of this condition, locking means, to be described later, lock the mechanical linkage 93 against movement whenever a turn is made by means of the turn control potentiometer 86, and hence all of the wipers operated by this linkage are held in center position and no signal is put in tending to return the ship to its original heading.

Considering now a portion of the procedure which must be followed before placing the system in operation by connecting the amplifiers 13, 14 and 15 to the servomotors 16, 17 and 18, it will be apparent that the wiper 88 of the turn control potentiometer 86 should first be centered so that no signal will be fed into the aileron and rudder networks 10 and 11 from the turn control bridge 85. The wipers 38 and 39; 138 and 139; and 238 and 239 of the centering potentiometers 34, 35; 134, 135; 234 and 235 respectively are also preferably in center position so that it will be possible to trim the ship by moving all of the control surfaces in either of their directions. The wiper 54 of the banking potentiometer 52, the wiper 57 of the banking acceleration potentiometer 55, and the wiper 142 of the rudder gyroscopically operated potentiometer 140 should also be centered so that the directional gyroscope 92 will have equal control in either direction in azimuth. The airplane itself should be trimmed so that it is flying in the proper attitude and on the proper heading; and since the control surfaces will then be adjusted so as to maintain the plane in its proper attitude and heading, it is important that under all these conditions that the signal from the networks 10, 11 and 12 to the amplifiers 13, 14 and 15 respectively be zero so that when the corresponding servomotors 16, 17 and 18 are connected to their respective amplifiers there will be no movement of any control surface which would tend to cause the plane to change its attitude or heading. Because of loading or other conditions, it may be necessary to use a certain amount of aileron control surface in order to hold the wings of the ship level; and in such a case a signal would be developed in the bridge 30 and transmitted on to the amplifier 13. This signal must be canceled by an opposing signal so that the aileron servomotor 16 will not be driven when it is connected to the amplifier 13; and to provide this opposing signal, switching means 91 is arranged so that when the amplifier is not connected to the aileron servomotor 16, it is connected to the aileron network balancing motor 77, this being a two-position switching means with no off position. The balancing motor 77 is a small reversible motor whose only function is to drive the wiper 74 across the resistor 73 of the potentiometer 72, and the characteristics of this motor are such that if there is a signal through the amplifier which would operate the servomotor 16, that same signal when going to the balancing motor will drive the latter so that the wiper 74 is moved in a direction to oppose and counteract the signal from the remainder of the network 10. As soon as the signal from the remainder of the network 10 is counteracted, the signal through the amplifier becomes zero and there is thus no signal to the balancing motor from the amplifier and movement of the wiper 74 is stopped. The switching means 91 may then be operated to connect the amplifier 13 to the servomotor 16 and there will be no movement of the servo motor which would drive the control surface and cause the ship to lurch. The operation of the balancing motors 177 and 277 with regard to the signal developed by the networks 11 and 12 respectively is the same, and it will thus be seen that it will be possible to operate the switching means 91, 191 and 291 to engage the control system on all the axes without there being any lurching of the plane or any violent movement of any of the control surfaces thereof.

Power circuit

In Figure 2 I have shown a power circuit for use with my control system, making use of several safety features not previously available. In the power system shown, a source of power such as the ship's batteries 301 or generators (not shown) or both is connected to the usual single wire power system used in planes, with one terminal of the battery grounded and the other terminal connected through the plane's master switch 302 to a bus bar 303. Connected to the ship's bus 303 is a system master switch 304 which energizes a system bus 339, and all power to the control system is controlled by this switch so that in case of emergency it is necessary only to open this switch and all operation of the control system immediately ceases. When the switch 304 is closed, power flows from it through the coil 305 of a current sensitive relay 306 and then through conductor 309 to the directional gyroscope 92 where it energizes the motor 307, shown in Figure 3, driving the rotor of the gyroscope. The characteristics of the motor 307 are such that when it is initially energized and during the major portion of the time it is accelerating, the amount of current it draws is considerably above the amount drawn when it has reached its final operating speed. The current sensitive relay 306 has a pair of contacts 308 which are normally in a closed posi-

tion, but which are opened when the current through the coil 305 exceeds a predetermined value. The current sensitive relay 306 is adjusted so that upon starting the motor 307 and continuing until it has reached a speed sufficient to give the gyroscope an appreciable spatial rigidity, the contacts 308 remain open; but when the gyroscope has acquired the necessary rigidity the contacts are closed and a circuit is completed through them from the master switch 304 through conductor 310, to a torque motor 323 whose function and operation are hereinafter described.

To provide the alternating current necessary to operate the control networks previously described, an inverter 311 is provided which has its input circuit connected to the master switch 304 and to ground, and has its alternating current output circuit connected to the various transformers of the control network and may also be connected as shown to the amplifiers 13, 14 and 15 for use as a power source therein should that appear desirable. If direct current power is also desired in the amplifiers they may likewise be connected to the switch 304 and be energized therefrom.

The closing of switch 304 also energizes the vertical gyroscope 94 which has connected in series with its power lead an operating coil 312 of a current sensitive relay 313, the contacts 314 of which are normally opened but are adapted to be closed when the gyroscope is first energized and to remain closed until it has reached a speed sufficient to provide the necessary spatial rigidity.

When the switch 304 is closed it will thus be seen that the directional gyroscope 92 is energized and the motor therein starts to rotate and bring the gyroscope up to speed; and as it approaches its normal operating speed contacts 308 of relay 306 are closed and the torque motor 323 is energized. At the same time that the directional gyroscope 92 is energized, the inverter 311 is energized, and starts to deliver alternating current to the networks 10, 11 and 12 which are thereby placed in operative condition, the amplifiers 13, 14 and 15 are energized by the inverter and/or the power flowing directly from switch 304, and the vertical gyroscope 94 is likewise energized so that the rotor therein begins to revolve and is erected to a vertical position by means not shown. It will be apparent that during this warm-up period, while the gyroscopes are erecting and attaining their spatial rigidity, the servomotors 16, 17 and 18 should not be connected to their respective amplifiers 13, 14 and 15, since the transient conditions present during this period would cause erratic movement of the control surfaces with resulting undesired movement of the plane. During this period, therefore, the output of the amplifiers 13, 14 and 15 is directed by the switching means 91, 191 and 291 to the respective balancing motors 77, 177 and 277 so that the networks 10, 11 and 12 are continually balanced as these transient conditions may require. When these transient conditions have passed and it is desired to have this system control the flight of the plane, a switch 315 may be thrown to complete a circuit from the master switch 304 through switch 315, conductor 320, the contacts 316 of a relay 317, and conductor 321 to the operating coil 318 of a relay 319. The energization of the coil 318 of the relay 319 acts to operate the switching means 91, 191 and 291 so that the output of the amplifiers 13, 14 and 15 is transferred from the corresponding balancing motors 77, 177 and 277 to the corresponding servomotors 16, 17 and 18. Under these conditions the networks 10, 11 and 12 have been balanced so that no signal is sent from them to the amplifiers which would cause the servomotors to drive the control surfaces to new positions when the control system is engaged.

If, in spite of its balancing motor, for some reason or other one of the networks is unbalanced and is transmitting a signal to its amplifier, a signal will be sent to the corresponding centering motor and that same signal would be sent to the servomotor should the relay 319 be operated to transfer the amplifier output to the servomotor. This would cause the plane to lurch and is generally undesirable.

To prevent the engaging of the system until each network is balanced, the relay 317 is provided with a number of coils each one of which is capable of attracting the armature of the relay and thus opening the circuit between the contacts 316. One of the coils of the relay 317 is connected through conductor 358, contacts 314 of the current sensitive relay 313, and conductor 359 to the master switch 304 so that should the vertical gyroscope be rotating at a speed below that needed to give it sufficient rigidity, the contacts 314 will be closed and the associated coil in the relay 317 will be energized and thereby open the contacts 316 to prevent the operations of the relay 319. I have connected the remaining coils of the relay 317 so that each one is in parallel with a corresponding winding of one of the balancing motors, so that should any one of the balancing motors be receiving a signal tending to drive it in either direction when an attempt is made to engage the control system, at least one of the windings of the relay 317 will be energized and the contacts 316 will be open and so prevent the operation of relay 319 to transfer the output of the amplifier to their respective servo motors. In case the plane is flying in rough air, minor changes in its attitude will be occurring continuously; and if no provision were made for this, these changes in attitude would cause the relay 317 to be energized almost continuously because of the slight changes of position required of the balancing motors. To take care of this contingency, I provide a time delay means on the relay 317 which may take the form of a time delay slug 322 which will prevent the operation of the relay until one or more of the coils has been continuously energized for an appreciable time. Multiple coil relays and time delay slugs are well known in the art, and any suitable units may be used.

It will thus be seen that I have provided a system in which the closing of one switch energizes the control networks and starts the rotating units, but engagement of the system is prevented until the rotating units are up to speed and the control networks are balanced. In this connection it might be well to note that in airplane electrical systems the voltage available at the main bus 303 often varies over a wide range, and under these conditions it may be difficult if not impossible to adjust the current sensitive relay 313 in series with the vertical gyroscope 94 so that the contacts 314 will be open immediately upon the gyroscope's being erected and coming up to speed and not before then. If voltage fluctuations cause these troubles, it is possible, of course, to substitute a time delay relay of any suitable type, adjustable to the proper time interval, for the current sensitive relay 313. A portion of the circuit shown in Figure 2 is shown with a time delay switch in place of the current-sensitive relay, in Figure 2*a*. In this Figure I have shown a time delay switch 391 which may be of any suitable type. such as thermal, motor driven, etc., and which is energized when the vertical gyroscope 94 is energized, to complete a circuit through conductors 358 and 359 to a winding of multiple-coil relay 317. After a predetermined period of time, sufficient for the rotor of the gyroscope 94 to come up to speed, the circuit is opened, and the remainder of the operation is the same as that previously described. Timing relays generally work very well, but motor driven time delays are usually not so satisfactory since from their nature, if the system's master switch 304 is opened and then immediately closed, the pilot must wait the full period of the time delay before he can reengage the control system, although it will be aparent that the momentary interruption of current to the vertical gyroscope will not have caused it to lose sufficient speed to require erecting again, or to have lost its spatial rigidity.

Turning now to the directional gyrosope and the elements associated with it which are now of interest, some

of these elements are a torque motor 323, a directional arm lock or D. A. L. 324, and a directional panel 325. As may be seen in Figure 4, the directional gyroscope 92 includes an enclosed rotor 326 having the motor 307 therein (not shown) pivotally mounted for rotation about a horizontal axis and supported by a cardan ring 327 which is rotatable about a vertical axis passing through its center. A cardan gear 328, concentric with the vertical axis of rotation of the cardan 327, is mechanically connected to the latter so that the two rotate as a unit; and slip rings 329 axially spaced from the gear 328 and concentric therewith provide means for supplying power to the motor 307 within the housing 326. Above the slip rings 329 and rigidly connected to the cardan gear 328 and concentric therewith is a clutch drum 330 which may be engaged by a ring 331 to which is attached a directional arm 332. The ring 331 is split and provided with expanding means (not shown) which permit the clutch drum 330 and the ring 331 to cooperate to form a clutch which may be engaged or disengaged to permit movement of the directional arm 332 as the cardan ring 327 turns about its vertical axis. Stops, not shown, are provided which limit the movement of the directional arm 332, and when the arm has reached one of the limiting stops, further movement of the cardan ring 327 causes the clutch drum 330 to slip within the ring 331.

As is well known to those familar with gyroscopes, when an external force is applied to a gyroscope tending to turn it about an axis perpendicular to its axis of rotation, the gyroscope actually turns or precesses about an axis perpendicular to the axis of rotation of the gyroscope and perpendicular to the axis about which the force is acting. As is also known to those familiar with gyroscopes, a gyroscope tends to retain its heading in space unless caused by external forces to change this heading. While the rotor of the gyroscope 326 does exhibit these characteristics of spatial rigidity, the friction of the cardan gear 328, slip rings 329, directional arm 332, and associated equipment is sufficient to cause the cardan ring 327 and hence the gyroscope 326 to be rotated about a vertical axis when the ship is turned in space. However the rotation of the cardan ring about its vertical axis applies a torque or turning force to the gyroscope 326 and causes the latter to move about a horizontal axis perpendicular to its axis of rotation so that the gyroscope bobs or tilts.

This bobbing or tilting of the gyroscope may be used to control means for overcoming the effect of the frictional drag on the gyroscope and this may be done by providing a wiper 333 which may make contact with any one of a series of sectors 334, 335, 336 and 337 mounted on an insulating plate 338 which is attached to the cardan ring 327. The sectors 334 and 335 are so located that they will be contacted by the wiper 333 when that end of gyroscope has tilted below the horizontal and contacts 336, and 337 are so located that they will be contacted by the wiper 333 when that end of the gyroscope has tilted above the horizontal, thus leaving a space between sectors 335 and 336 on which the wiper 333 will ride when the gyroscope is horizontal.

To provide the restoring force necessary to keep the rotor 326 of the gyroscope horizontal, the torque motor 323 is provided, consisting of a continuously running motor 340 driving a pair of gears 341 and 342 so that they rotate in opposite direction. As shown in Figure 4, the lower surfaces of gears 341 and 342 are provided with clutch plates 343 and 344 respectively, and axially movable into engagement with these clutch plates are the associated clutch plates 345 and 346 respectively. Connected to the movable clutch plates 345 and 346 are pinion gears 347 and 348, respectively, both of which are continuously meshed with gear 349 which drives gear 350, the latter gear being meshed with the cardan gear 328. Normally, the clutch discs 345 and 346 do not engage their associated discs 343 and 344, but when, as shown in Figure 4, disc 346 engages its associated disc 344, the gear 342 attempts to rotate the gear 348 and this attempted rotation is transmitted through gears 349 and 350 to the cardan gear 328, thereby attempting to rotate the gyroscope rotor 326 about its vertical axis and hence causing it to tilt about its horizontal axis. To move the clutch discs 345 and 346 into engagement with their associated discs 343 and 344 respectively, a pair of electromagnets 351 and 352 which have armatures 353 and 354 are provided. The armatures 353 and 354 are adapted to bear against the ends of their respective gears 347 and 348 and urge the associated movable clutch discs 345 and 346, respectively, into engagement with clutch discs 343 and 344 when their associated electromagnets 351 and 352 are energized.

The electromagnets 351 and 352 are selectively energized by means of the wiper 333 and contacts 334, 335, 336 and 337; and as shown in Figure 4, electromagnet 352 is energized by reason of the fact that wiper 333 is making contact with sector 334 and hence gear 342 is attempting to drive the cardan gear 328 which will result in the rotor 326 of the gyroscope being returned to horizontal position. Sectors 334 and 337 are connected to separate slip rings 329 and sector 335 is connected through a resistor 356, shown in Figure 3, to the same slip ring that sector 334 is connected, while sector 336 is connected through a resistor 357 to the same slip ring that sector 337 is connected. The effect of resistors 356 and 357 is to provide a smaller impulse to the electromagnets 351 and 352 when the inner sectors 335 and 336 are contacted by the wiper 333 than when the outer sectors 334 and 337 are similarly contacted. This means that a smaller amount of torque will be applied to the cardan gear 328 when the gyroscope rotor 326 has tipped a small amount than when it has tilted through a larger angle. Stops 360 and 361 are provided in the cardan ring 327 to prevent the gyroscope rotor 326 from tilting too far before the torque motor 323 can return the rotor to its horizontal position.

The directional gyroscope which I have just described in and of itself forms no part of my invention since such gyroscopes are well known in the art, and the description has merely been included in order to point out more clearly the features and the operation of the improvements I have developed therefor.

The operation of the directional arm lock 324 may now be more clearly understood, reference being had to Figures 2, 3 and 4 of the drawing. As has previously been mentioned, for proper operation of the control system it is necessary that the wipers 54 and 57 of the banking potentiometer 52 and the banking accelerating potentiometer 55 and the wiper 142 of the rudder gyroscopically operated potentiometer 140 must be centered with respect to the ends of the resistors of their respective potentiometers before the control system is engaged, and when turns are being made with the control potentiometer 86 while the system is engaged. Since the operation of the directional gyroscope 92 and its associated potentiometers is to keep the plane headed so that the wipers of these potentiometers remain in substantially their center position during normal flight, all that remains to be done is to insure that the wipers will remain in this position when a turn is made by the control potentiometer 86. As previously described, the wiper 88 of the control potentiometer 86 is manually operated, and mounted on the same shaft as the wiper 88 is a cam member 363 which operates a switch 364 so that the contacts of the latter are opened when the wiper 88 is in its mid position and closed when it is moved to either side thereof. The directional arm lock 324 consists of a solenoid 365 which, when energized, attracts a clamping bar 366 which then moves to bear against arm 367 which, like arm 332, forms a portion of the mechanical linkage 93 connecting the directional gyroscope 92 to its various potentiometer wipers. The arm 367, which is normally movable back and forth as indicated by the arrows in Figure 3, will then be clamped so

that it can no longer move, and slippage will then occur between the clutch drum **330** and the ring **331**. To energize the solenoid **365**, a circuit is completed from system bus **339**, through switch **364**, conductor **362**, solenoid **365**, and through a wiper **371** and contact **374**, described later, to ground. When the contacts of switch **364** are opened the solenoid **365** is deenergized and the arm **367** is released.

To provide means for centering the wipers of the various directional gyro controlled potentiometers before the control system is engaged, I have made use of the motor **340** of the torque motor **323**, and the electromagnets **351** and **352** associated therewith. This centering is accomplished only when the system is not engaged and is controlled by a pair of wipers **370** and **371** connected to a gyroscopically operated arm which may be an extension of directional gyro arm **332**, the wipers cooperating with a series of contacts **372**, **373** and **374**. The wiper **370** may bear against contact **372** or **373** or neither of them, this latter condition occurring when the wipers of the potentiometers operated by the directional gyroscope are centered; and wiper **371** bears against contact **374** when the wipers of the potentiometers are centered. The contacts **372**, **373** and **374** together with the wipers **370** and **371** may be conveniently located within the panel which houses the potentiometers operated by the directional gyroscope, this housing being referred to as the directional panel **325**. Contact **374** is grounded, and when wiper **371** makes contact therewith a circuit is completed to the coil **365** of the directional arm lock **324**. A circuit may be traced (Figure 3) from ground to the contact **374**, through the wiper **371**, through the solenoid coil **365**, and, when the control system is engaged, through switch **364** and switch **304** to the energized side of the plane's electrical system as indicated by the bus **303**. When switch **315** is in the autopilot disengage position shown in Figure 2, i. e., so that it energizes conductor **362**, it shorts switch **364** to energize coil **365** of directional arm lock **324** from whence the circuit is completed through the wiper **371** and contact **374** as previously mentioned.

In addition to energizing the solenoid **365** of the directional arm lock **324**, the wiper **371** and contact **374** cooperate to energize the winding **380** of a relay **381**, the other end of whose winding is connected, with the ungrounded side of the torque motor **340**, through the contacts **308** of the current sensitive relay **306** to the master switch **304**. This relay has two pairs of normally open contacts **382** which interrupt the circuit from the slip rings **329** to the electromagnets **351** and **352** of the torque motor **323**, the result being that in order for the wiper **333** on the end of the gyroscope rotor **336** to have any effect upon the horizontal position of that rotor when contact is made with one of the sectors **334**, **335**, **336** or **337**, the wiper **371** must bear against contact **374** and energize the relay **381** to complete the circuit to the electromagnets **351** and **352**.

When wiper **371** is not touching contact **374**, wiper **370**, which moves with wiper **371**, will then be touching either contact **372** or **373**; and these latter contacts are connected to selectively energize the electromagnets **351** and **352** of the torque motor **323**. The operation under these conditions can be best understood by referring to Figures 4 and 5 wherein it is seen that wiper **370** is bearing against contact **372** and wiper **371** is not touching contact **374**. The contacts **382** of relay **381** are thus open and, as seen in Figure 4, electromagnet **352** is energized so that gear **342** attempts to drive the cardan gear **328**. As previously explained, this will cause the rotor **326** of the gyroscope to tilt, but since sectors **334**, **335**, **336** and **337** are disconnected from their respective electromagnets **351** and **352**, the tilting will cause no corresponding action of the electromagnets, and the rotor **326** will continue to tilt until it hits one of the stops **360** or **361**. As is normal under such conditions, when a torque is applied to a gyroscope and the latter tilts until it hits a stop, further application of that torque will cause rotation of the gyroscope in the direction of the applied torque, which may then be of greatly reduced value. Consequently, when wiper **370** bears against contact **372**, electromagnet **352** is energized, clutch plate **346** moves into engagement with clutch plate **344** and gear **342** drives the cardan gear **328** causing the gyroscope rotor **326** to turn and the whole assembly of gyroscope, cardan ring **327**, cardan gear **328** and associated equipment to rotate, thereby moving wiper **370** towards center. When wiper **370** reaches its mid position, its connection with contact **372** is broken, releasing the electromagnet **352** and stopping the driving of the cardan gear **328**; at the same time wiper **371** has made connection with contact **374**, energizing the locking solenoid **365** and also energizing the relay **381** which thereupon restores the normal circuit of the wiper **333** and contacts **334**, **335**, **336** and **337** so that the gyroscope rotor **326** is then returned to its horizontal position. Since locking solenoid **365** is energized as soon as the wipers **370** and **371** return to their mid position, the directional arm **367** is immediately locked in position and there is thus no possibility of angular momentum carrying the cardan gear **328** past its desired position and hence driving wiper **370** beyond its mid point so that it bears against contact **373**.

To prevent wiper **370** and contacts **372** and **373** from completing a circuit which would cause the torque motor **323** to revolve the rotor **326** and center the various potentiometers controlled by it when the plane is being controlled by the automatic pilot, I provide a relay **385** having an operating coil **386**, a normally open contact **387**, a normally closed contact **388**, and a movable contact **389** adapted to bear against either of the other two contacts. Movable contact **389** is grounded, and normally closed contact **388** is connected to wiper **370**, so that when coil **386** is not energized, wiper **370** is grounded and the operation is as previously described. Normally open contact **387** is connected to wiper **371**, and thus when coil **386** is energized, wiper **571** is grounded through normally open contact **387** and movable contact **389** irrespective of whether wiper **371** is bearing against contact **374** or not. Thus, when operating coil **386** is energized, movable contact **389** opens the ground circuit to normally closed contact **388** and grounds normally open contact **387**, thereby preventing wiper **370** from completing a circuit to electromagnets **351** or **352**, and also continuously grounding wiper **371** so that relay **381** is continuously energized to close contacts **382** and maintain the normal circuits to the electromagnets **351** and **352** from slip rings **329**. To energize operating coil **386**, one end thereof is grounded and the other end is connected by conductor **390** to conductor **320**, and hence relay **385** is operated when switch **315** is in the position wherein switching relay **319** may be energized. In this way, the potentiometer wipers controlled by the directional gyroscope **92** will automatically be centered when the switch **315** is in the position shown in Figure 2, but when the switch is thrown to its other position and the autopilot is engaged, the centering circuits are broken and any deviation of the plane from its assigned heading will cause a movement of the wipers controlled by the directional gyroscope **92**, and they will be returned to their centered position only by return of the plane to its original heading.

Operation of the power system

It may now be appreciated that my invention has simplified the operation of a control system such as this, since the operations which a pilot must perform in order to engage this system have been enormously simplified and reduced over those necessary in previous systems.

To prepare the system, assuming that the plane is airborne and that the master switch **302** is closed, the pilot must first close control system master switch **304** and

then trim the plane manually so that it has the desired attitude and heading. When the system is so prepared, power is immediately applied to the directional stabilizer **92**, the inverter **311**, the amplifiers **13**, **14** and **15**, and the vertical gyroscope **94**. The bridge networks **10**, **11** and **12** are thus energized and the amplifiers **13**, **14** and **15** are energized and warming up; the torque motor **323**, because of the large initial current through the current sensitive relay **306**, is not energized; and the similar large current drain by the vertical gyroscope **94** through the current sensitive relay **313** has closed the contacts **314** thereof and energized the corresponding coil of the relay **317** so that the contacts **316** thereof are open. The relay **319** is thus not energized, and the switching means **91**, **191** and **291** are thus transmitting the power output of the amplifiers **13**, **14** and **15** to the corresponding balancing motors **77**, **177** and **277** so that as the amplifiers warm up, any signals developed in the networks **10**, **11** or **12** will be used to drive the balancing motors so that these signals are balanced out. As the directional gyroscope **92** gathers speed, the current it draws will be reduced and eventually the contact **308** of the current sensitive relay **306** will be closed and the torque motor **323** energized. Were it not for this delay, and if the torque motor were energized at the same time that the directional gyroscope were energized, the gyroscope would have no spatial rigidity and the torque applied to it by the torque motor would rotate it very rapidly and thereby cause the rotor **326** to bang violently against its stop and probably damage the bearings of the rotor.

When the torque motor **323** is energized, the automatic centering means consisting of the wipers **370**, **371** and their associated contacts cause the mechanical linkage **93** to be driven so that the wipers **54** and **57** of the banking potentiometer **52** and the banking accelerating potentiometer **55** respectively, and the wiper **142** of the rudder gyroscopically operated potentiometer **140** are placed in their center positions. In addition, the directional arm lock **324** is energized as soon as these positions are attained and hence there will be no further movement of these wipers until the system is engaged.

When the plane has been trimmed to the satisfaction of the pilot, the directional gyroscope **92** has attained a sufficient speed to allow the contacts **308** to close and energize the torque motor **323**, the vertical gyroscope **34** has attained a sufficient speed to enable the contacts **314** of the relay **313** to open, and the balancing motors **77**, **177** and **277** have balanced out all but momentary and transient signals from the aileron, rudder, and elevator networks **10**, **11** and **12**, the contacts **316** of the relay **317** will then be closed and the pilot may throw switch **315** to complete a circuit through contacts **316** and coil **318** of relay **319** and then to ground, thereby operating the switching means **91**, **191** and **291** to transfer the power output of the amplifiers **13**, **14** and **15** to the servo motors **16**, **17** and **18**. Thus, all that the pilot has to do is to throw the master switch **304**, and then, after a period sufficient to enable the gyroscopes to assume their proper speed, throw switch **315** and the control system is then engaged and flying the plane. Changes in attitude and changes in heading may be taken care of as previously described, and it will thus be seen that I have provided a control system which operates to provide an extremely sensitive control of great flexibility while at the same time providing this system with an operating procedure so simple that a pilot who has had no experience in its use may become very proficient with only a few minutes instructions.

Because of the superiority of electrically operated automatic pilots, I have shown and described my invention as it may be applied to one of these. It is particularly adapted to such a system, though it may be seen that with slight modifications my invention may be applied to other control systems using fluid or mechanically operated elements, and the signals referred to in the claims may be electrical, fluid, or mechanical. While I have shown and described a preferred form of my invention, it is apparent that modifications thereof are possible, and I do not wish to be limited to the form shown except as indicated by the following claims.

I claim as my invention:

1. In a modulating control system, in combination, a device to be positioned, power means for positioning the same, a controller, responsive means controlled by the relative positions of said controller and said power means for positioning said power means in accordance with the condition of said controller, means for connecting and disconnecting said responsive means from said power means to enable positioning said device in such position that said responsive means demands repositioning of said device, and compensating means connected to said responsive means when said connecting and disconnecting means are operated to disconnect said power means therefrom and also automatically operated by said responsive means to satisfy such demand without further movement of the device, whereby upon reconnection of said power means to said responsive means, no movement of the device to be controlled takes place.

2. A motor control system which includes: a main controller; a rebalancing controller; a motor to be controlled, and operatively connected to said rebalancing controller; means actuated by the unbalance between said main controller and said rebalancing controller and connectable to said motor to operate said motor to reduce said unbalance; means to shift the point of unbalance between said main controller and said rebalancing controller at which said first means will cause said motor to operate, said means being connectable to said first means and operated thereby; and means for selectively connecting said first means to said motor or to said second means.

3. A modulating control system which includes: a device to be positioned; motor means for positioning said device; a gyroscope including means for spinning the rotor thereof; means controlled by said gyroscope for controlling the operation of said motor means; and means operated upon the energization of said spinning means to prevent said gyroscope from exercising control for a period of time whereby to give said rotor time to come up to speed.

4. A modulating control system which includes: a device to be positioned; motor means for positioning said device; a gyroscope having means operable to spin the rotor thereof; control means having an element operated by said gyroscope for controlling the operation of said motor means; and means controlled by the speed of the rotor to prevent the control of said motor means by said gyroscope until said rotor is spinning at a predetermined speed.

5. A structure for use with an electrically actuated modulating apparatus in which a variable impedance controller and a variable impedance rebalancer positioned by a positioning motor means that drives a device to be positioned are connected in an electrical network to produce a signal when the position of said device does not correspond to the condition of said controller, the signal being transmitted to the positioning motor means by a motor control means to cause actuation of the positioning motor means to reposition said variable impedance rebalancer to nullify the signal and to reposition said device, comprising, a balancing variable impedance connectable to said network and adjustable to nullify any such signal without repositioning of said rebalancing impedance, a balancing motor for driving said balancing variable impedance, and switching means connected to said balancing motor and connectable to said motor control means and said positioning motor means for selectively connecting said motor control means to said balancing motor or said positioning motor means.

6. An electrical system of control, comprising, in combination, a variable impedance type of controller, electrically controlled reversible motor means, a device to be positioned thereby, a rebalancing variable impedance means operated by said motor means, a signal producing means including an electrical network having said variable impedance controller and said variable impedance means therein for producing a signal when the value of said rebalancing variable impedance means is not properly correlated to the value of said variable impedance controller, a signal responsive means connected to said signal producing means and in control of said motor means, a motor driven balancing variable impedance means also in said network, and switch means selectively operable to connect said reversible motor means or the motor of said motor driven balancing impedance means to said signal responsive means, whereby when the motor of said motor driven variable impedance means is connected to said signal responsive means the network is maintained in such condition that no signal is produced regardless of the relative values of said variable impedance controller and said rebalancing variable impedance means so that upon disconnection of said signal responsive means from the motor of said motor driven variable impedance and connection of said reversible motor means to said signal responsive means no movement of said device to be positioned results.

7. In a modulating control system, in combination, a device to be positioned, power means for positioning the same, a controller, responsive means controlled by the relative conditions of said controller and power means for positioning said power means in accordance with the condition of said controller, means for connecting and disconnecting said responsive means from said power means to enable positioning said device in such position that said responsive means demands repositioning of said device, compensating means operable to satisfy such demand without movement of the device, and means actuated when said demand has been satisfied by said compensating means to operating said connecting means to connect said power means to said responsive means.

8. In a modulating control system, in combination, a device to be positioned, power means for positioning the same, a controller, responsive means controlled by the relative conditions of said controller and power means for positioning said power means in accordance with the condition of said controller, means for connecting and disconnecting said responsive means from said power means to enable positioning said controlled device in such position that said responsive means demands repositioning of said controlled device, compensating means connected to said responsive means and operable to satisfy such demand without movement of the controlled device, and means actuated when said demand has been satisfied by said compensating means to disconnect said compensating means from said responsive means and to operate said connecting means to connect said power means to said responsive means.

9. An electrical system of control, comprising, in combination, a gyroscopically operated variable impedance type of controller, electrically controlled reversible motor means, a device to be positioned thereby, a rebalancing variable impedance means operated by said motor means, a signal producing means including an electrical network having said variable impedance controller and said variable impedance means therein for producing a signal when the value of said rebalancing variable impedance means is not properly correlated to the value of said variable impedance controller, a signal responsive means connected to said signal producing means and in control of said motor means, a motor driven balancing variable impedance means also in said network, switch means selectively operable to connect said reversible motor means or the motor of said motor driven balancing impedance means to said signal responsive means, whereby when the motor of said motor driven variable impedance means is connected to said signal responsive means the network is maintained in such condition that no signal is produced regardless of the relative values of said variable impedance controller and said rebalancing variable impedance means so that upon disconnection of said signal responsive means from the motor of said motor driven variable impedance and connection of said reversible motor means to said signal responsive means no movement of said device to be positioned results, and means to prevent the operation of said switch means for a period of time after the energization of said gyroscope whereby to give the rotor of said gyroscope time to acquire a predetermined rate of spin.

10. An electrical system of control, comprising, in combination, a gyroscopically operated variable impedance type of controller, electrically controlled reversible motor means, a device to be positioned thereby, a rebalancing variable impedance means operated by said motor means, a signal producing means including an electrical network having said variable impedance controller and said variable impedance means therein for producing a signal when the value of said rebalancing variable impedance means is not properly correlated to the value of said variable impedance controller, a signal responsive means connected to said signal producing means and in control of said motor means, a motor driven balancing variable impedance means also in said network, switch means selectively operable to connect said reversible motor means or the motor of said motor driven balancing impedance means to said signal responsive means, whereby when the motor of said motor driven variable impedance means is connected to said signal responsive means the network is maintained in such condition that no signal is produced regardless of the relative values of said variable impedance controller and said rebalancing variable impedance means so that upon disconnection of said signal responsive means from the motor of said motor driven variable impedance and connection of said reversible motor means to said signal responsive means no movement of said device to be positioned results, and means to prevent the operation of said switch means until the rotor of said gyroscope is spinning at a predetermined rate.

11. In a modulating control system, in combination: a device to be positioned; power means for positioning the same; a plurality of gyroscopically operated controllers; means controlled by the relative conditions of said controllers and said power means for positioning said power means in accordance with the condition of said controllers; means for connecting and disconnecting said responsive means from said power means to enable positioning said controlled device in such position that said responsive means demands repositioning of said controlled device; compensating means operable to satisfy such demand without movement of the controlled device; means operable when said demand has been satisfied by said compensating means to operate said connecting means to connect said power means to said responsive means; and means preventing the operation of said last means for a period of time after the energization of one of said gyroscopes whereby to give the rotor of said gyroscope time to acquire a predetermined rate of spin.

12. An operating device for a control system having condition responsive elements connected to form a balanceable electrical network, motor control means adapted to operate in accordance with signals from said network, and motor means connectable to said motor control means and adapted to drive condition controlling means, said operating device including: means adapted to mechanically center one of said condition responsive elements so as to place it in the center of its response range; balancing means consisting of a signal generator connected in series with the output of said network and the input of said motor control means, and a balancing motor con-

nectable to said motor control means and adapted to vary the signal from said signal generator in response to signals from said motor control means, said balancing means providing a signal opposing said signal from said network; means normally connecting said motor control means to said balancing motor, but operable to disconnect said balancing motor and connect said motor means to said motor control means; and means adapted to prevent the operation of said last means to connect said motor means to said motor control means if said balancing means has not opposed said bridge signal so that said network is balanced.

13. An operating device for a control system having condition responsive elements connected to form an electrical network, motor control means adapted to operate in accordance with signals from said network, and motor means connectable to said motor control means and adapted to drive condition controlling means, said operating device including: means adapted to place said motor control means, said condition responsive elements, and said network in operating but non-controlling condition; means adapted to mechanically center one of said condition responsive elements so as to place it in the center of its response range; balancing means consisting of a center-tapped resistor whose ends are connected to a power supply and whose center-tap is connected to an output lead of said network, a potentiometer connected in parallel with said center-tapped resistor and whose wiper is connected to an input terminal of said motor control means, and a balancing motor connectable to said motor control means and adapted to move said wiper in response to signals from said motor control means, said balancing means providing a signal opposing said signal from said network; means normally connecting said motor control means to said balancing motor, but operable to disconnect said balancing motor and connect said motor means to said motor control means; and means adapted to prevent the operation of said last means to connect said motor means to said motor control means if said balancing means has not opposed said bridge signal so that said motor control means requires non-operation of said motor means.

14. An operating device for a control system having a plurality of condition responsive elements connected to form a network of electrical bridges, one set of said elements being controlled by a directional gyroscope, and another set of said elements being controlled by a vertical gyroscope, said system having motor control means adapted to operate in accordance with signals from said network, and motor means connectable to said motor control means and adapted to drive condition controlling means, said operating device including: a switch adapted to control the energization of said network, said motor control means, and the rotors of said gyroscopes; a torque motor adapted to maintain the rotor of said directional gyroscope in a substantially horizontal position; means adapted to be operated when the rotor of said directional gyroscope has attained a speed sufficient to give it some spatial rigidity and adapted to complete a circuit to said torque motor; means associated with said directional gyroscope to interrupt the normal action of said torque motor and to cause said torque motor to turn the rotor of said gyroscope about a substantially vertical axis and thereby center said condition responsive elements controlled by said directional gyroscope, said means then operating a locking means adapted to hold said gyroscopically controlled elements in centered position, and simultaneously to operate a relay which completes the normal circuit to said torque motor; an automatic balancing means for reducing the signal from said motor control means to zero, said balancing means including a signal generator connected to one of the input terminals of said motor control means, and a balancing motor connectable to the output of said motor control means and adapted to control said signal generator in accordance with signals from said motor control means, said balancing means introducing a signal opposing the resultant signal from said condition responsive elements; means adapted to complete a circuit if the rotor of said vertical gyroscope has not attained a predetermined speed; switching means adapted to close a pair of contacts when said last means does not complete its circuit and when said centering motor is not energized; a relay adapted to transfer the output of said motor control means to said first motor means or to said centering motor; and a switch adapted to disengage said locking means associated with said directional gyroscope, and to energize the operating coil of said last mentioned relay when the contacts of said switching means are closed, thereby connecting said first motor means to said motor control means and disconnecting said centering motor therefrom, and hence causing said control system to operate and control said condition controlling means.

15. An operating device for a control system having a plurality of condition responsive elements connected to form a network of electrical bridges, one set of said elements being controlled by a directional gyroscope, and another set of said elements being controlled by a vertical gyroscope, said system having motor control means adapted to operate in accordance with signals from said network, and motor means connectable to said motor control means and adapted to drive condition controlling means, said operating device including: a switch adapted to energize said network, said motor control means, and the rotors of said gyroscopes; a current sensitive relay in series with the rotor of said directional gyroscope and having a pair of normally closed contacts adapted to be held open until said rotor has attained a speed sufficient to give it some spatial rigidity, whereupon said contacts are closed and complete a circuit to a torque motor adapted to maintain said gyroscope rotor in its horizontal position; means associated with said directional gyroscope to interrupt the normal action of said torque motor, said interrupting means including a wiper adapted to engage a contact when the condition responsive elements controlled by said directional gyroscope are centered, and a second wiper adapted to engage selectively a second and a third contact when said elements are not centered, said second wiper and contacts being adapted to cause said torque motor to turn the rotor of said gyroscope about a substantially vertical axis and thereby center said condition responsive elements, and said first wiper and contact being adapted to operate a locking means to hold said gyroscopically controlled elements in centered position, and simultaneously to operate a relay which completes the normal circuit to said torque motor; an automatic balancing means for reducing the signal from said motor control means to zero, said balancing means including a center-tapped resistor whose center tap is connected to one output terminal of said network and whose ends are connected to a source of power, a potentiometer connected in parallel with said resistor and whose wiper is connected to one of the input terminals of said motor control means, and a balancing motor connectable to the output of said motor control means and adapted to move the wiper of said potentiometer in accordance with signals from said motor control means, said balancing means introducing a signal opposing the resultant signal from said condition responsive elements; a current sensitive relay connected in series with the rotor of said vertical gyroscope and having a pair of contacts normally open but closed when the current drawn by said rotor is greater than a predetermined value; a relay having a plurality of operating coils and a time-delay unit thereon, one of said coils being connected through said second current sensitive relay contacts and energized when said current to said vertical gyroscope exceeds a predetermined value, the remainder of said coils being individually connected in parallel with said centering motor so that at least one of said coils is ener-

gized when said centering motor is energized, the contacts of said relay being normally closed, but opened by the energization of one or more of the coils of said relay, said time delay unit preventing the opening of said contacts unless said coil is energized an appreciable time; a relay adapted to transfer the output of said motor control means to said first motor means or to said centering motor; and a switch adapted to disengage said locking means associated with said directional gyroscope, and to energize the operating coil of said last mentioned relay when the contacts of said multiple coil relay are closed, thereby connecting said first motor means to said motor control means and disconnecting said centering motor therefrom, and hence causing said control system to operate and control said condition controlling means.

16. A structure for use with an electrically actuated modulating apparatus in which a variable impedance controller and a variable impedance rebalancer positioned by a positioning motor means that drives a device to be positioned are connected in an electrical network to produce an unbalancing signal when the position of said device does not correspond to the condition of said controller, the signal being transmitted to the positioning motor means by a motor control means to cause actuation of the positioning motor means to reposition said variable impedance rebalancer to nullify the signal and to reposition said device, comprising, a balancing variable impedance connectable to said network and adjustable to nullify any such signal without repositioning of said rebalancing impedance, a balancing motor for driving said balancing variable impedance, switching means connected to said balancing motor and connectable to said motor control means and said positioning motor means for selectively connecting said motor control means to said balancing motor or said positioning motor means, and means responsive to the unbalance of said network resulting in the flow of current to said balancing motor for holding said switching means in its position in which said motor control means is connected to said balancing motor as long as current flows to said balancing motor.

17. Automatic balancing means for a control system having a balanceable electrical condition responsive network which produces a signal whose magnitude and phase is determined by the direction and amount of displacement of a condition responsive device from a predetermined point, said condition responsive network having associated therewith a motor, condition affecting means driven by said motor, and a motor operating means adapted to drive said motor so as to cause said condition affecting means to be driven to permit the return of said condition responsive device to said predetermined point, said balancing means including: a voltage source; a potentiometer and a resistance connected in parallel across said voltage source to form therewith a bridge circuit: means connecting an output element of said condition responsive network to the midpoint of said resistor of said bridge, the wiper of said potentiometer being connected to said motor operating means; a second motor adapted to position said potentiometer wiper; and means associated with said motor operating means whereby when said first motor is disengaged, said second motor is driven by said motor operating means to cause said potentiometer wiper to assume a position wherein the signal from said condition responsive network is balanced out by the signal from said bridge.

18. A protective device for a control system having a condition responsive element, a balanceable motor control means actuated by said element in accordance with the changes thereof, motor means adapted to be connected to or disconnected from said motor control means and to be controlled thereby, and balancing means connected to said motor control means and adapted to oppose the effects of changes of said condition responsive element, said protective device including: a relay having a time delay means associated therewith, and connectable to said motor control means in place of said motor means and to be operated thereby upon unbalance of said control means; operable means adapted to connect said motor control means to said relay or to said motor means; and means controlled by said relay and adapted to prevent the operation of said operable means to prevent the disconnection of said relay from said control means and the connection of said motor means with said control means if said relay is energized.

19. A protective device for a control system having a normally operable condition responsive element, a motor control means actuated by said element in accordance with the changes thereof not affecting its normal operation, motor means adapted to be connected to said motor control means and to be controlled thereby, and balancing means connected to said motor control means and adapted to oppose the effect resulting from changes of said condition responsive element, said protective device including: an element responsive to the operative or non-operative condition of said condition responsive element; a multiple coil relay having a time delay means associated therewith, one coil of said relay being connected to said element responsive to said operative or non-operative condition and the remainder of said coils being connectable to said motor control means in place of said motor means, the contacts of said relay being operated by the energization of one or more of said coils; means adapted to connect said motor control means to said coils of said multiple coil relay or to said motor means; and means adapted to prevent the disconnection of said motor control means from said multiple coil relay and the connection of said motor control means with said motor means if one or more of said coils of said relay is energized.

20. An automatic pilot for an aircraft having sets of control surfaces adapted to vary the attitude and heading of said airplane, said pilot including: servomotor means adapted to operate each of said sets of control surfaces; condition responsive means adapted to control the operation of said servomotor means; a condition responsive element in said condition responsive means operated by a directional gyroscope; balancing means adapted to shift the relative operated relationship between said condition responsive element and said servomotor means, and connectible to said condition responsive means for operation thereby; means adapted to center with respect to its response range, said condition responsive element operated by said directional gyroscope; switching means adapted to connect said condition responsive means to said servomotor means or to said balancing means; and means to prevent the operation of said switching means to disconnect said balancing means and connect said servomotor means to said condition responsive means if said condition responsive means requires operation of said servomotor means.

21. An automatic pilot for an aircraft having sets of control surfaces adapted to vary the attitude and heading of said airplane, said pilot including: servomotor means adapted to operate each of said sets of control surfaces; condition responsive means adapted to control the operation of said servomotor means; a gyroscopically operated condition responsive element in said condition responsive means; balancing means adapted to shift the relationship of the operations of said condition responsive element and said servomotor means, and connectable to said condition responsive means for operation thereby; switching means adapted to connect said condition responsive means to said servomotor means or to said balancing means; and means to prevent the operation of said switching means to disconnect said balancing means and connect said servomotor means to said condition responsive means if said condition responsive means requires operation of said servomotor means, or if said

gyroscope has not acquired a predetermined operating speed.

22. An automatic pilot for an aircraft having sets of control surfaces adapted to vary the attitude and heading of said airplane, said pilot including: servomotor means adapted to operate each of said sets of control surfaces; an operable condition responsive means adapted to control the operation of said servomotor means, balancing means adapted to shift the extent of operation relationship between said condition responsive means and said servomotor means, and connectable to said condition responsive means for operation thereby; switching means adapted to connect said condition responsive means to said servomotor means or to said balancing means; and means to prevent the operation of said switching means to disconnect said balancing means and connect said servomotor means to said condition responsive means if said condition responsive means requires operation of said servomotor means.

23. A protective device for a control system having motor control means operated by a condition responsive element and motor means connectable to said motor control means, said protective device including: balancing means adapted to oppose the requirements of said condition responsive element, said means being connectable to said motor control means in place of said motor means; means adapted to connect said motor control means to said balancing means or to said motor means; and means adapted to permit the operation of said connecting means to disconnect said balancing means and connect said motor means only when said motor control means does not require operation of said motor means.

24. A protective device for a control system having a plurality of motor means each adapted to operate a separate condition controlling member, a motor control means for each of said motor means and connectable thereto, a balanceable condition responsive system for each of said motor control means, each motor means having its own motor control means and condition responsive system, and a gyroscope controlling one of the elements of one of said condition responsive systems for unbalancing said system, said protective device including: balancing means in each condition responsive system adapted to oppose the requirements of each of said condition responsive systems and also connectable to said motor control means for operation thereby; switching means adapted to transfer the control imposed by said motor control means from said balancing means to said motor means; and means preventing the operation of said switching means to connect said control means to any of said motor means if any of said balanceable systems is unbalanced and to cause motor control means to effect operation of its balancing means, or if said gyroscope has not acquired a predetermined operating speed.

25. An operating device for a control system having a condition responsive gyroscopically operated element, a balanceable motor control means connected to said element to be unbalanced thereby and motor means connectable to said control means to be operated thereby and driving a follow up element in said balanceable control means, said operating device including: balancing means in said control means and having an operable means therefor connectable to said control means to be operated thereby to shift the responsive point between said gyro operated element and said follow up element thereof; switching means adapted to connect said control means to said operable means for said balancing means or to said motor means; and means to prevent the operation of said switching means to connect said motor means to said control means if the rotor of said gyroscope has not acquired a predetermined speed or if said control means has not been balanced.

26. An operating device for a control system having a condition responsive gyroscopically operated element, a balanceable control means operated by said element to unbalance said control means, and motor means connectable to said control means to be operated thereby and driving a follow up element in said control means, said operating device including: means automatically to center said gyroscopically operated element with respect to its response range; and balancing means connectable to said control means and operable to shift the relative positions of said gyroscopically operated element and said follow up element at which said elements unbalance said control means.

27. A motor control apparatus comprising: a control means including a main controller and a rebalancing controller; a motor to be controlled and operatively connected to said rebalancing controller; actuable means actuated from said control means by the unbalance between said main controller and said rebalancing controller and connectable to and disconnectable from said motor to operate said motor to reduce said unbalance; additional controller means for rebalancing said control means upon movement of said main controller and alternatively connectable to said actuable means to be operated thereby; and means for selectively connecting said actuable means to said motor or to said additional means.

28. Control apparatus comprising: a device to be positioned; means for positioning said device; control means for said positioning means including a controller, a gyroscope having an electrically driven rotor whose impedance varies with the speed of said rotor and connected to said controller; and means responsive to the change in said impedance and interposed between said control means and said positioning means for disassociating said control means from said positioning means.

29. Control apparatus comprising: an electrically operated motor means; a gyroscope having means to spin the rotor thereof; motor control means having an element operated by said gyroscope and adapted to effect the operation of said motor means upon such element operation; means operated by said motor to render said control means ineffective; and means operative upon energization of said spinning means to prevent operation of said motor means by said control means until said gyro has come up to speed.

30. A control apparatus comprising: a motor means, a gyroscope having means to spin the rotor thereof; control means having an element operated by said gyroscope and adapted to control the operation of said motor means, and means controlled by speed of said rotor to prevent the control of said motor means by said control means.

31. Control apparatus comprising: a motor means, a gyro having an electrically operative rotor the impedance of which varies with the speed of said rotor, control means having an operable connection with said motor means and having an element operated by said gyro, and means electrically connected in series with said rotor and operative upon a change in impedance of the rotor to control said operable connection.

32. Control apparatus comprising: a motor means; control means adapted to be connected to and disconnected from said motor means; a control mechanism having an operative and a non-operative state and adapted to control said control means; an operation initiating element in said mechanism; an additional element in said mechanism opposing the effect of said initiating element; an operable means adapted to be connected to or disconnected from said control means also, for operating said additional element; actuable means for connecting said control means with said motor means or with said operable means, and further means controlled by said operable means to prevent actuation of said actuable means to effect disconnection of said control means from said operable means and connection to said motor means until said control mechanism has been placed in a non-operative state.

33. Control apparatus for an aircraft having a control surface comprising: operating means for said control sur-

face, control means for said operating means including a plurality of operable controllers, means responsive to changes in the course of the aircraft for operating one controller, a gyroscope means responsive to changes in attitude of the aircraft for operating a second controller, actuable means for connecting said control means to said operating means, and means controlled by the speed of said gyroscope rotor for preventing the actuation of said actuable means until said gyroscope rotor has attained a certain speed of rotation.

34. Control apparatus comprising: a gyroscope having a power driven rotor, balanceable control means having a controller operated by said gyroscope and a follow up controller, means for operating said follow up controller, operable means for connecting said control means to said operating means, and means operable upon application of power to turn the rotor for preventing operation of said operable means until said gyroscope rotor has attained a predetermined speed.

35. In combination with a gyroscope mounted on a support and having a rotor, means for rotating said rotor, motor means operable upon relative movement of said support with respect to said rotor about an axis other than the axis of rotation of said rotor, and means energized with said rotor for preventing operation of said operable motor means until said rotor has attained a predetermined speed of rotation.

36. Control apparatus for an aircraft having a control surface comprising: operating means for said control surface, control means for said operating means including an initiating and a follow up controller, operable means for connecting or disconnecting said control means with said operating means, means responsive to a condition of said aircraft for operating said initiating controller, means for connecting said operating means with said follow up controller, and means effective when said operable means has disconnected said control means from said operating means and operated by said control means for maintaining said initiating controller in predetermined relation with respect to the follow up controller.

37. Control apparatus comprising: a plurality of condition responsive elements each responsive to a different condition for generating a plurality of signals, means connected with said elements so that changes in said elements are combined to provide a single signal, means responsive to said signal, operating means for a condition controlling means connectable to said responsive means, balancing means including additional means alternatively connectable to said resposive means, means to transfer said single signal effects on said responsive means to said condition controlling means or to said additional means, and a signal generating means operated by said additional means and connected so that its signal opposes the combined signals of said condition responsive elements so that said single signal is reduced to zero.

38. Apparatus for selectively controlling the attitude of a craft in accordance with a signal and permitting direct manual control of the craft, comprising an attitude-responsive device for supplying a voltage component varying in response to variations of attitude of the craft, means for producing a variable voltage component, a servo mechanism responsive to said attitude-responsive voltage component and said variable voltage component for varying the attitude of said craft in accordance with relative variations of said components, means for supplying a balancing voltage component; means for disabling said servo mechanism from controlling the attitude of said craft; and further means responsive to said voltage components for varying said balancing voltage component in accordance with said attitude-responsive voltage component during the period during which said servo mechanism is disabled.

39. Apparatus for selectively controlling the attitude of a craft in accordance with a signal and selectively permitting direct manual control of the craft attitude, comprising attitude reference signal providing means for detecting variations of attitude of said craft, servo means responsive to said reference means for providing a follow-up signal and maintaining said craft in a selected attitude, balancing means operatively coupled to at least one of said means and providing a signal equal in magnitude but opposite in sense for varying the attitude at which said attitude reference means and said servo means maintain said craft, and means for disabling said servo means from controlling the attitude of said craft and also operating said balancing means in response to changes in attitude for varying the attitude-maintaining characteristics of said servo means and attitude reference means in accordance with craft attitude variations for preconditioning said servo means for the institution of servo control of said craft.

40. Control apparatus comprising: a motor means; control means adapted to be connected to and disconnected from said motor means; a balanceable control mechanism adapted on unbalance to control said control means; an operation initiating element in said control mechanism; an additional element in said control mechanism for opposing the effect of said operation initiating element; means for operating said additional element; actuable means for connecting said control means to said motor means; and means responsive to said control means for rendering inoperative said actuable means until said control mechanism has been placed in balance by operation of said additional element.

41. Control apparatus having a balanceable motor control means adapted to be unbalanced with a change in response of a condition responsive element and also having a motor means connectable to said motor control means for operation thereby on unbalance thereof and adapted to drive condition controlling means as a result of the unbalance of said control means, said control apparatus including: balancing means in said control means alternatively with said motor means connectable to said motor control means and operable thereby and also adapted to oppose the unbalance arising out of said change in response of said condition responsive element so as to cause said motor control means to become balanced; means to connect said motor controlling means to said motor means or to said balancing means; and means effective as the result of operation of said motor controlling means to prevent the connection of said motor controlling means to said motor means if said balancing means has not caused said motor control means to become balanced.

42. In a condition control system having a condition responsive element, motor control means adapted to operate in accordance with the changes in said condition responsive element due to changes in said condition, and motor means connectable to said motor control means and adapted to drive conditon controlling means: means adapted to mechanically position said condition responsive element so that it is substantially at the center of its response range; balancing means connectable to said motor control means and adapted to be not only controlled thereby but also to oppose the changes of said condition responsive element in said control means so as to cause said motor control means to be in balanced and non-operative condition; selective means to connect said motor controlling means to said motor means or to said balancing means; and further means responsive to operation of said motor control means to prevent the connection of said motor controlling means to said motor means if said balancing means has not caused said motor control means to attain non-operative condition.

43. Apparatus for selectively controlling the attitude of a craft in accordance with a signal and selectively permitting direct manual control of the craft attitude, comprising a balanceable potentiometer network having attitude reference means for detecting variations of attitude of said craft operating one potentiometer, servo means controlled by said network to be responsive to said refer-

ence means for maintaining said craft in a selected attitude and operating a second potentiometer, means in said network operatively connected to at least one of said potentiometers for varying the attitude at which said attitude reference means and said servo means maintain said craft, means for disabling said network from controlling said servo means, and means alternatively controlled by said potentiometer network for varying the attitude-maintaining characteristics of said servo means and attitude reference means in accordance with craft attitude variations for preconditioning said servo means for the institution of servo control of said craft.

44. A structure for use with a balanceable control apparatus of the type in which a main controller and a follow-up controlled device, which controls a condition sensed by the main controller conjointly control an operable controlling mechanism to maintain it in a null or unoperated condition to cause the controlling mechanism to position the controlled device in accordance with changes in the condition of said main controller and terminate operation of said controlling mechanism, said mechanism comprising an amplifier and a balanceable electrical control signal providing network connected to the amplifier wherein the main controller and the follow-up controlled device are relatively remotely positioned in said network, said mechanism also comprising, adjustable means in said controlling mechanism network remote from said main controller and operable to also place said controlling mechanism in a null condition, automatic means adapted to respond to said controlling mechanism for positioning said adjustable means, and selective switching means connected to said controlling mechanism for selectively connecting either said automatic means or said controlled device to said controlling mechanism.

45. An automatic pilot for aircraft having a control surface for controlling the movement of said aircraft about a control axis comprising a control device having an output which is normally balanced but which becomes unbalanced in opposite senses in response to the character of input signals supplied thereto, a signal generator for supplying input signals to said control device position-maintaining means for actuating said signal generator to cause unbalance of said control device in a sense dependent upon the direction of displacement of said aircraft about said control axis, synchronizing means responsive to the sense of unbalance of said control device for restoring the balance of said control device independently of the position of said position maintaining means relative to said aircraft, servomotor means responsive to the sense of unbalance of said control device for actuating said control surface, and switching means for selectively disabling said synchronizing means and said servomotor means, said switching means having a synchronizing position in which said servomotor means is disabled to permit said synchronizing means to balance said control device for the position then occupied by said aircraft, and an engaging position in which said synchronizing means is disabled to permit said servomotor means to stabilize said aircraft in a position occupied thereby at the time said switch means is actuated from the synchronizing to the engaging position.

46. In an automatic pilot for aircraft having a control surface for moving said aircraft about a control axis, a control device having an output which is normally balanced but which becomes unbalanced in opposite senses in response to the character of input signals supplied thereto, a position-maintaining means, a signal generator actuated by said position-maintaining means, means for supplying input signals to said control device in accordance with the output of said signal generator to unbalance said control device in a sense dependent on the direction of displacement of said aircraft about said control axis, servomotor means responsive, when operative, to the sense of unbalance of said control device for actuating said control surface to stabilize said aircraft about said control axis, reversible motor means responsive, when operative, to the sense of unbalance of said control device for adjusting the input to said control device to restore balance of said control device independently of the position of said position-maintaining means relative to said aircraft, and switching means having a synchronizing position and an engaging position for selectively disabling said reversible motor means and said servomotor means, said switching means operating in said synchronizing position to disable said servomotor means whereby said reversible motor means balances said control device for the position then occupied by said aircraft, and said switch means operating in said engaging position to disable said reversible motor means whereby said servomotor means actuates said control surface to stabilize said aircraft in the position occupied thereby at the time said switching means is actuated from said synchronizing position to said engaging position.

47. In an automatic pilot for aircraft having a rudder for steering said aircraft about a control axis, a control device having an output which is normally balanced but which becomes unbalanced in opposite senses in response to the character of input signals supplied thereto, an azimuth-position maintaining means, signal generator means, means for varying the output of said signal generator in accordance with the azimuth position of said aircraft relative to said azimuth-position maintaining means, a course setter for additionally varying the output of said signal generator independently of the position of said azimuth-position maintaining means, means for supplying input signals to said control device in accordance with the output of said signal generator to unbalance said control device in either sense, servomotor means responsive, when operative, to the sense of unbalance of said control device for actuating said control surface to stabilize said aircraft in azimuth, reversible motor means responsive, when operative, to the sense of unbalance of said control device for actuating said course setter to restore balance to said control device independently of the position of said azimuth-position maintaining means, and switching means having a synchronizing position and an engaging position for selectively disabling said reversible motor means and said servomotor means, said switching means operating in said synchronizing position to disable said servomotor means whereby said reversible motor means balances said control device for the azimuth position then occupied by said aircraft, and said switch means operating in said engaging position to disable said reversible motor means wherey said servomotor means actuates said control surface and stablizes said aircraft in azimuth in the position occupied thereby at the time said switching means is actuated from said synchronizing position to said engaging position.

48. An automatic pilot for aircraft having a control surface for controlling movement of said aircraft about a control axis comprising a control device having an output which is normally balanced but which becomes unbalanced in opposite senses in response to the character of input signal supplied thereto, a position-responsive signal generator and a trim signal generator for supplying input signals to said control device, position-maintaining means for actuating said position-responsive signal generator to cause unbalance of said control device in response to the direction of displacement of said aircraft about said control axis, synchronizing means responsive to the sense of unbalance of said control device for varying the output of said trim signal generator to restore balance of said control device independently of the position of said position-maintaining means relative to said aircraft, servomotor means responsive to the sense of unbalance of said control device for actuating said control surface, and switching means for selectively disabling said synchronizing means and said servomotor means, said switching means having a synchronizing position in which said servo-

motor means is disabled to permit said synchronizing means to balance said control device for the position then occupied by said aircraft and an engaging position in which said synchronizing means is disabled to permit said servomotor means to stabilize said aircraft in the position occupied thereby at the time said switching means is actuated from said synchronizing position to said engaging position.

49. Control apparatus comprising: an electric motor means; amplifier control means adapted to be connected to and disconnected from said electric motor means; a balanceable electrical signal providing control mechanism adapted on unbalance to control said amplifier control means; an operation initiating element in said balanceable control mechanism; an additional element in said balanceable control mechanism for opposing the effect of said operation initiating element; means for operating said additional element; actuatable switch means for connecting said amplifier control means to said electric motor means; and time delay means responsive to said control means for rendering said actuatable switch means inoperative to connect said amplifier control means to said motor means if said control mechanism has not been balanced by operation of said additional element.

50. Control apparatus for an aircraft having attitude controlling means, comprising: motor means for operating said attitude controlling means; control signal responsive means adapted to be connected to and disconnected from said motor means; a balanceable signal providing control mechanism adapted on unbalance to control said control means; an operation initiating element in said balanceable control mechanism; an additional element in said balanceable control mechanism for opposing the effect of said operation initiating element; means for operating said additional element; actuatable means for connecting said signal responsive control means to said motor means; and time delay relay means having an operating winding responsive to said control means for rendering said actuatable means inoperative to connect said amplifier control means to said motor means unless said control mechanism has been placed in balance by operation of said additional element.

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