

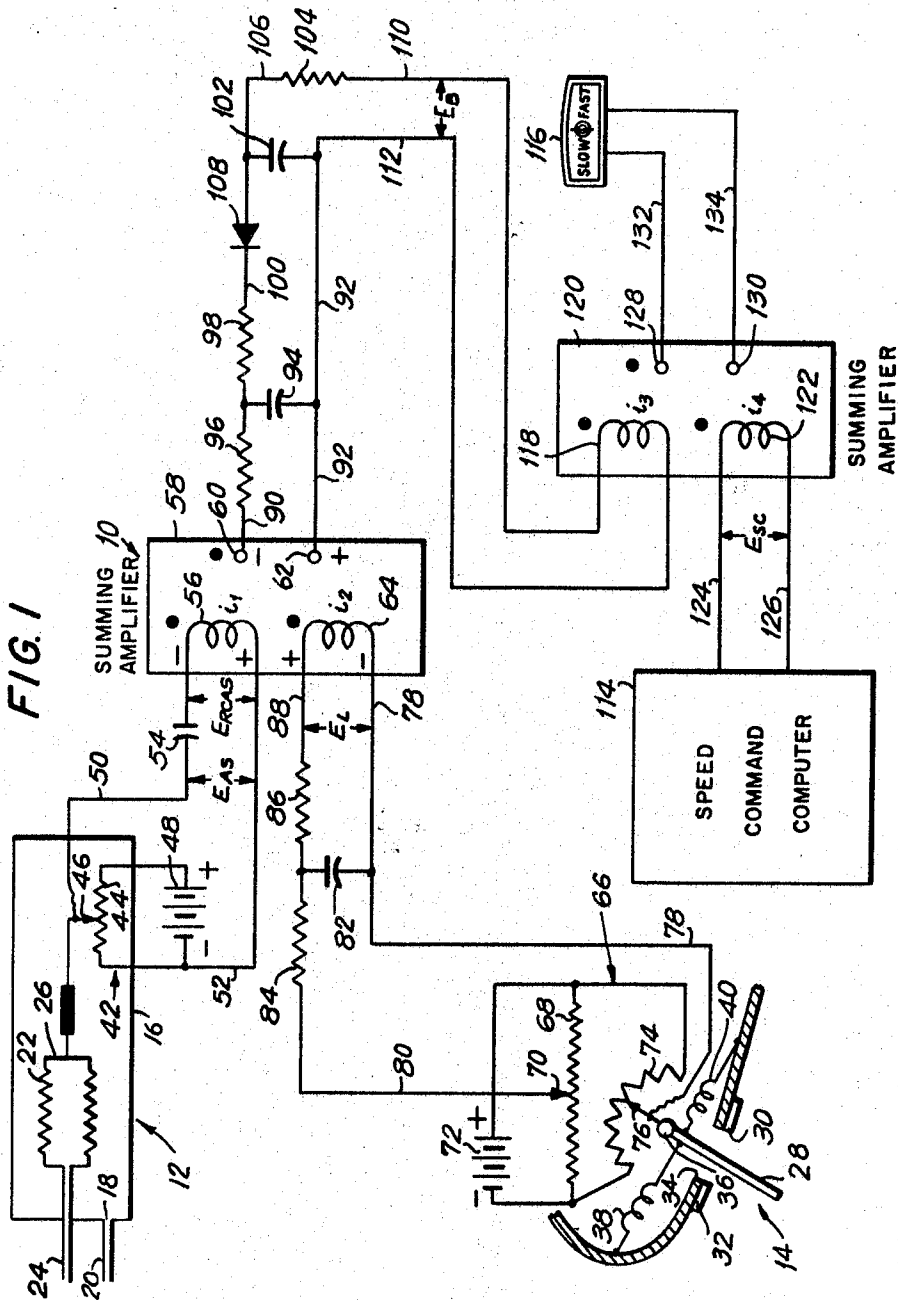
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Filed March 4, 1965

L. M. GREENE

3,327,972

AIRPLANE INSTRUMENT FOR FURNISHING A BIAS SIGNAL TO OFFSET THE
 EFFECTS OF FORWARD COMPONENTS OF GUSTS DURING LANDING APPROACH
 March 4, 1965

3 Sheets-Sheet 1



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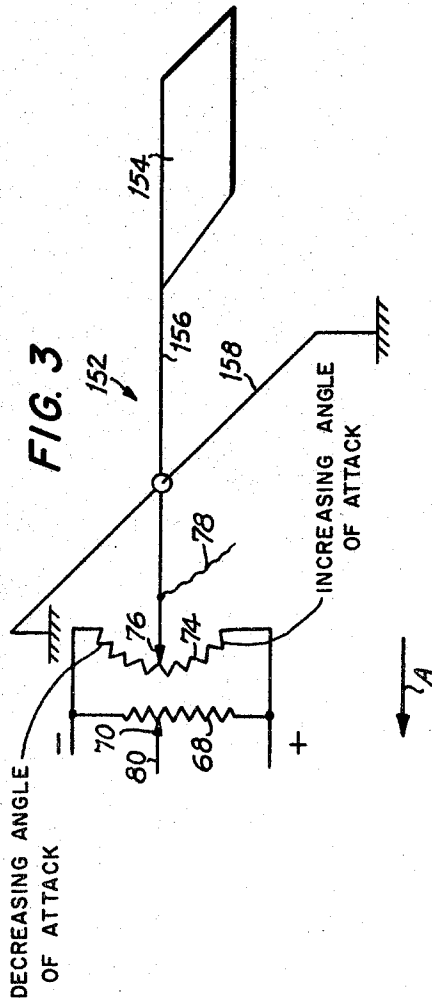
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3 Sheets-Sheet 2



DECREASING ANGLE
OF ATTACK

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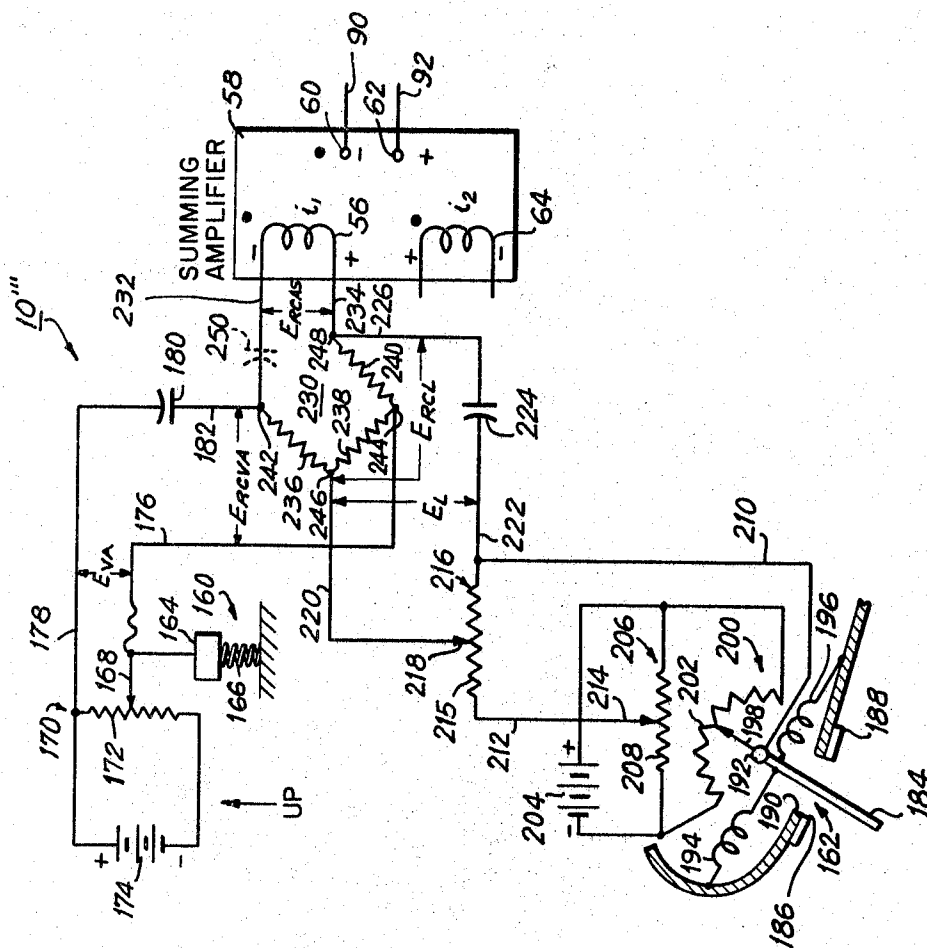


FIG. 4

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AIRPLANE INSTRUMENT FOR FURNISHING A BIAS SIGNAL TO OFFSET THE EFFECTS OF FORWARD COMPONENTS OF GUSTS DURING LANDING APPROACH

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Filed Mar. 4, 1965, Ser. No. 437,055

25 Claims. (Cl. 244-77)

This invention relates to an airplane instrument for furnishing a bias signal to offset the effects of forward components of gusts during landing approach.

Shifting winds or gusts cause fluctuations in the instantaneous air speed of an airplane. For example, a head gust, i.e., a sudden rearward short term increase in the speed of a local air mass relative to an airplane, increases the instantaneous air speed of the airplane. Just prior to the incidence of the gust the airplane in smooth air has a certain instantaneous forward air speed relative to the moving or stationary local air mass, to which upon the occurrence of the head gust is added the sudden rearward increase in the speed of the local air mass. Since such a gust enhances air speed, it is referred to as a "positive" gust. A tail gust, on the other hand, constitutes a sudden forward short term increase in speed of the local air mass and hence decreases the air speed of the airplane. Accordingly, it is referred to as a "negative" gust. It is the fore-and-aft (relative to an airplane) component of any gust that has such a positive or negative effect on the air speed of the airplane.

During a landing approach when an airplane is flying at an air speed or lift value which is low, in order to obtain a desirable low landing speed, but yet is safely above the minimum air speed or lift value necessary to maintain the airplane in flight, or correspondingly, when the airplane is flying at a desirable angle of attack which is high for the purpose of enabling operation at a desirable low landing speed, but yet is safely below the maximum angle of attack at which stall would occur, a negative gust, which is to say, a gust having a negative component, creates a problem in that it momentarily, for the duration of the gust, tends to give rise to too low an air speed or lift value, or too high an angle of attack. Such tendency must be overcome by the application of a higher level of power, i.e., an advance in throttle setting, so as to keep the air speed, lift value and angle of attack at safe desirable levels at all times throughout a landing approach. A consequent disadvantage is that the amount of power increase required to nullify the fluctuation in air speed or lift value or angle of attack is excessive and the ensuing surging of the engines is both uncomfortable and unsafe.

At present, an airplane pilot, in order to avoid engine surging, which arises from throttle compensation for gusts on an individual gust basis, makes it a practice to counter gusts in an empirical quasi-arbitrary manner. Under conditions wherein a train of gusts of random intensity, duration, direction and occurrence is encountered, a pilot will fly the airplane at an average speed that is somewhat faster than minimum safe air speed, so that negative gust fluctuations will not bring about a dangerous air speed, lift value or angle of attack. In this manner the amount of power manipulation that is required is considerably reduced. Nevertheless, this empirical solution of an arbitrarily selected increased speed is not satisfactory because it relegates the degree of overspeed to the pilot's discretion which may not always be accurately exercised and which will vary from time to time and from individual to individual.

It is a principal object of my present invention to provide an instrument which will furnish a bias signal to offset the effects of negative gusts during landing approach which instrument will operate in a predetermined precise

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and accurate fashion so as not to leave to pilot discretion the power regulation that is to be exercised to offset gusting.

It is another object of my invention to provide an instrument of the character described which is reliable, efficient and safe in operation, so that the security of airplanes and airplane passengers may properly be entrusted thereto.

It is another object of my invention to provide an airplane instrument of the character described which will respond rapidly to the first negative gust, so that the air speed of the airplane can be quickly increased to avoid the initial unsafe condition.

It is another object of my invention to provide an airplane instrument of the character described wherein the increased speed to compensate for negative gusting is maintained smoothly so long as negative gusting prevails, that is to say, an instrument in which the director, i.e., command, signal to offset negative gusting is maintained for a period of time sufficiently prolonged to offset a succession of negative gusts whereby intermittent engine surging is avoided.

It is another object of my invention to provide an airplane instrument of the character described in which once negative gusting has occurred and the air speed of the airplane has been increased to offset the effects thereof, a clamping level is established to which subsequent negative gusts are compared and wherein further increases in air speed will be commanded only if the negative gusting exceeds the clamping level thus tending to minimize the effect of negative gusts following an initial negative gust.

It is another object of my invention to provide an airplane instrument of the character described in which the aforesaid clamping level is variable as a function of the average actual air speed or lift value or angle of attack of the airplane which has resulted from obeying the command signal that initially was created by the negative gusting condition.

It is another object of my invention to provide an airplane instrument of the character described in which the increased air speed command signal is slowly reduced after negative gusting ceases, so that the airplane will be restored to normal equilibrium condition in the flight maneuver that is being carried out, to wit, landing approach.

It is another object of my invention to provide an airplane instrument of the character described which does not respond to positive gusts and therefore will not call for a reduction in commanded speed (director air speed signal) because of a positive gust, although it will permit a gradual reduction in the increased air speed command signal after the negative gusting condition has passed.

It is another object of my invention to provide an airplane instrument of the character described in which the variable clamping level substantially eliminates fluctuating speed command signals once a safe average air speed or lift value or angle of attack has been reached.

It is another object of my invention to provide an airplane instrument of the character described which constitutes relatively few and simple components and which is light in weight and reliable in operation.

Other objects of my invention in part will be obvious and in part will be pointed out hereinafter.

My invention accordingly consists in the features of construction, combinations of elements and arrangements of parts which will be exemplified in the instruments hereinafter described and of which the scope of application will be indicated in the appended claims.

In the accompanying drawings in which are shown various possible embodiments of my invention,

FIG. 1 is a schematic circuit diagram of an airplane instrument embodying my present invention for furnishing an air speed director signal which, inter alia, is a func-

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tion of negative gusting conditions, including both an initial negative gust and the integrated effect of a series of negative gusts;

FIG. 2 is a diagram illustrating a modification of FIG. 1 in which the prevailing average lift condition of the airplane is derived from an air speed sensor instead of from a lift vane as in FIG. 1;

FIG. 3 is a diagram illustrating an angle of attack sensor which can be used instead of the lift vane shown in FIG. 1; and

FIG. 4 is a diagram illustrating another modification of FIG. 1 in which the rate of change of air speed of the airplane is derived by computation from the outputs of sensors that are responsive to variables other than air speed and of which the air speed is a function, specifically vertical acceleration and lift value, rather than, as in FIG. 1, from the output of a sensor that is directly responsive to air speed.

In general, I carry out my invention by providing a first means the output of which is a function of the rate of change of air speed and by providing a second means the output from which is a function of the prevailing average lift condition of the airplane.

The first means may directly sense rate of change of air speed, or, more conventionally, it may directly sense air speed and by computation, to wit, differentiation, as with a series capacitor if the air speed is represented by voltage, derive the rate of change of air speed. Alternatively the first means may provide a rate of change of air speed signal that is derived by computation from the outputs of plural sensors that are individually responsive to variables other than air speed but of which air speed is a function. For example, air speed is a function of vertical acceleration and angle of attack; it also is a function of vertical acceleration and lift value. Hence, if sensors are already in place that are responsive to vertical acceleration and to angle of attack or lift value, as they are on many airplanes, and if no sensor is in place that is responsive to air speed, rate of change of air speed can be obtained by combining the outputs of such plural sensors and by differentiation, the combining being in a proper proportion to yield a signal that is the equivalent of a signal that would be obtained by directly measuring rate of change of air speed (fluctuation in air speed) or by measuring change in air speed and differentiating the same.

The second means having an output that is a function of the prevailing average lift condition of the airplane may sense any property which is related to lift condition and provides an output that is an average (slowly responsive) function thereof. For example, the property sensed by the second means may be the lift value as determined by the position of a lift vane or the angle of attack as determined by the position of an angle of attack vane or the air speed of the airplane as determined by an air speed measuring device or as determined by computation from variables of which air speed is a function. The output from the second means must be nulled with respect to a predetermined desirable value of air speed or a predetermined desirable value of lift or a predetermined desirable value of angle of attack, so that it is a function of the deviation from null. The output from said second means is damped, so that such output by having its speed of response slowed down indicates an average condition extending over at least one second and preferably a few seconds, for example, five seconds, whereby this second output does not suddenly vary from moment to moment. Phrased differently, the output from the second means has a delayed response, the period of delay, i.e., the averaging period, preferably being greater than the median gust frequency, which is about one second, so that the output from the second means is far less sensitive to gusts than is the output from the first means.

The outputs of the first and second means are compared in a suitable summing means, i.e., a computer, and

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the output from such summing means is fed to an integrator (a storage means) through a polarizing device which restricts the signals fed to the integrator to signals that indicate the presence of a negative gust condition for which a speed correction should be made. In other words, the signals reaching the integrator are restricted to signals that indicate a reduced air speed condition, this being equivalent to an increased angle of attack condition and to a stall approaching condition. The summing means is characterized by its ability to quickly pass a negative gusting signal and the integrator is characterized by its ability to react quickly to a negative gusting signal issuing from the summing means, so that the integrator will rapidly furnish an output signal upon the occurrence of an initial negative gust. The integrator further is so constructed that it will tend to maintain for a prolonged span the condition it assumes upon receipt of the initial negative gusting signal, whereby it will over a period of time, such for instance, as a minute or two, supply a slowly decaying output signal that commands an increased air speed, whereby the engines will not be immediately reduced in power upon the termination of a negative gust and then quickly thereafter again increased in power upon the occurrence of a subsequent negative gust, but rather will continue to operate smoothly at a higher, slowly decreasing throttle (power) setting so as to create an increased air speed for a period of time long enough to avoid surging and so that the increased air speed will still prevail when fresh negative gusts are subsequently encountered after not too long a period of time, e.g., within a minute.

It will be observed that the airplane instrument actually forms part of a loop which includes the airplane; that is to say, upon the occurrence of a negative gust or series of such gusts the integrator will supply an air speed director signal which, when followed either automatically or by a pilot, will control, i.e., bring about an increase in, average air speed. This raised average air speed is reflected by an increase in the output of the second means above the predetermined desirable null condition. Since the summing means compares the outputs of the first and second means, subsequent negative gusts are measured against the increased average air speed or increased average lift value or lowered average angle of attack. So long as the negative gusts do not exceed the over-null clamping signal of the second means, the integrator will continue to furnish an approximately even signal, so that an average safe increased air speed or increased safe lift value or decreased safe angle of attack will be reached in equilibrium condition of the loop. Hence, subsequent negative gusts, once the average air speed has been increased to reach the command signal, will not tend to cause an undue further increase in the command signal.

The integrator means furnishes a bias output signal which may be used in any suitable manner, as for example, by feeding the same into a speed command computer that operates a utilization mechanism such as an air speed command meter or an automatic throttle control, or by adding the signal to the output of a speed command computer in a second summing means the output from which is led to a utilization mechanism.

Referring now in detail to the drawings, and, more particularly to FIG. 1, the reference numeral 10 denotes an airplane instrument constructed in accordance with my invention and illustrating an embodiment thereof wherein the sensors are of a mechanical nature and the variations in positions thereof are transduced to electrical quantities and in which suitable circuit means are operated by said electrical quantities to effect the various functions of the instrument.

Said instrument includes an air speed sensor 12 and a lift sensor 14 each having an affiliated transducer.

The air speed sensor 12 is conventionally, the same being of a dynamic pressure type. It includes a case 16 provided with a single opening 18 that connects the interior of the

case, as through a tube 20, to the prevailing static pressure, that is to say, the ambient static air pressure of the local air mass in which the airplane is situated. Also located within the case is a corrugated bellows 22 which expands or contracts as a function of the difference in pressures between the interior of the bellows and the interior of the case 16. A tube 24 extends from the bellows through a wall of the case, to which it is tightly sealed, to a forwardly facing Pitot head external to the airplane and sufficiently far from the airplane wing, propellers, engines and fuselage structure to be materially unaffected by turbulence created by the airplane. Thereby, the air pressure within the bellows is the total Pitot pressure, including the static pressure which is a function of altitude and air conditions and the dynamics pressure that is a function of indicated air speed. Hence, the wall 26 of the bellows will experience movement which is a function of Pitot pressure less static pressure and hence of dynamic air pressure, and, therefore, a function of prevailing indicated air speed.

The lift sensor 14 constitutes a vane 28 which extends through a slot 30 in a mounting plate 32 that is secured over an opening 34 in the skin of the wing adjacent the nose thereof. Located behind the skin of the wing is a transversely (spanwise) extending pivot 36 for the vane which is so positioned that it is behind the center of pressure of the vane. Suitable means, such, for instance, as a pair of opposed springs 38, 40, are provided to bias the vane to an equilibrium position between stops. Said vane is so located at the nose of the airplane that it is subjected to variation in pressure caused by shifting of the stagnation point over the nose of the wing. The particular location of the vane on the nose and the strength of the springs which bias the vane to a neutral position are not critical for proper performance of the instrument 10. The angular position assumed by said vane is a measure of the prevailing value of lift.

The output of the air speed sensor 12 as manifested by physical movement of the wall 26 is transduced into an electrical quantity, specifically voltage, by a potentiometer 42 consisting of a fixed winding 44 and a movable wiper 46. The wiper is driven by the wall 26. The ends of the potentiometer winding 44 are connected to a suitable D.C. source, for example, a battery 48. Hence, the voltage output E_{AS} across the lead 50 (connected to the wiper 46) and the lead 52 (connected to a terminal of the battery 48) will be a function of air speed. This output voltage is converted to rate of change of air speed voltage E_{RCAS} by a differentiating means, to wit, a series capacitor 54, which is inserted in the lead 50. Said voltage is fed to an input coil 56.

The polarization of the battery and the direction of movement of the wiper 46 responsive to change in prevailing air speed is such that upon a decrease in air speed the terminal of the coil 56 which is connected to the capacitor 54 will be negative with respect to the other terminal of the coil. These respective polarities are indicated by the plus and minus signs at opposite ends of the coil 56. The particular polarities selected are purely arbitrary. However, they supply reference polarities for other polarities later to be described. It will be apparent that at a constant air speed the voltage E_{RCAS} will be zero and that a voltage is developed across the coil 56 only by virtue of a change of the setting of the potentiometer wiper 46, this voltage decaying by passage of a current i_1 through said coil.

Said input coil 56 is one of plural input coils of a suitable first summing amplifier 58 such as a reset magnetic amplifier. A typical amplifier of this type is the Ferrac magnetic amplifier, manufactured by Airpax Electronics, Seminole Division, Fort Lauderdale, Fla. This type of amplifier includes a plurality of control inputs of which the input coil 56 is one, and a polar output the terminals 60, 62 of which are shown. Only two input control coils

56, 64 have been illustrated inasmuch as these are the only ones necessary for use in my instrument 10.

The output of the lift sensor 14 as manifested by physical movement of the vane 28 is transduced into an electrical quantity, specifically voltage, by a resistance bridge 66. Two legs of the bridge constitute a resistance voltage divider in the form of a potentiometer having a fixed winding 68 with a movable wiper 70. The ends of said potentiometer which are the input terminals of the bridge are connected to a suitable DC source, such as a battery 72. The other two legs of the bridge constitute a second potentiometer having a fixed resistance winding 74 and a wiper 76. The ends of the two potentiometers are connected to one another, so that said potentiometers are in parallel and both are connected across the battery 72. The wiper 76 is driven by the vane 28. With increased lift which is a result of increased air speed, the vane 28, as shown in FIG. 1, will turn in a counterclockwise direction, so that the potential on the bridge output lead 78 will become more negative (or less positive) with respect to the potential on the bridge output lead 80.

It will be apparent that the position of the wiper 70 furnishes a null point for the output on the leads 78, 80, that is to say, with a predetermined position of the wiper 70 in a certain position of the wiper 76 the output on the leads 78, 80 will be zero. At any position of the lift vane 28 indicating a higher lift value than the null value corresponding to the position of the wiper 70, the lead 78 becomes negative with respect to the lead 80 and vice versa. The wiper 70 is set either manually or automatically for any preselected desirable lift value, for example, a lift value corresponding to an air speed which is safely above, by a desirable amount, the minimum air speed during landing approach. If the lift value increases, as with an increase in air speed, above the null value the lead 78 will go negative with respect to the lead 80 by an amount which is a function of the value of lift in excess of the set null value represented by the set position of the wiper 70.

The output from the lift sensor 14 is delayed so that it is averaged and thereby is less sensitive to gusts than is the output from the air speed sensor 12. This can be accomplished in various manners. For instance, the movement of the vane 28 may be hydraulically restrained. As shown herein, the voltage across the leads 78, 80 is damped for averaging purposes by an RC filter circuit constituting a capacitor 82 connected across said leads, an input resistor 84 in the lead 80 and an output resistor 86 in the lead 88. The leads 78, 88 are connected to the input control coil 64 so that the voltage E_L (voltage that is a function of the deviations of averaged lift value from a preselected desirable null lift value) across said leads induces a flow of current i_2 therein and thus provides a second input to the summing amplifier 58 which now will be seen to have an input E_{RCAS} which is a function of the rate of change of air speed, and another input E_L which is a function of the deviation of average lift value from a null preselected desirable lift value. It will be noted that the currents i_1 and i_2 are summed in a like sense, that is, they are cumulative for increasing air speed, increasing lift value and decreasing angle of attack both of which latter parameters are associated with increasing air speed. Hence, the currents i_1 and i_2 will create opposing effects in the summing amplifier 58 when the current i_1 is representative of a negative rate of change of air speed and the current i_2 is representative of an increased average air speed (lift value) over the null air speed (lift value).

The values of the capacitor 82, resistors 84 and 86 and inductance 64 are so selected that they have an RC time constant of the several, e.g., five, seconds so that the current i_2 represents the average value of the lift over the null value for a period of several seconds.

The polarity signs indicated at opposite ends of the input coil 64 are those for a position of the lift vane 28 corresponding to an average lift value greater than the

preselected desirable null lift value set by the position of the wiper 70 and have been shown in this manner because this is the condition of the circuit shortly after the occurrence of a negative gust condition and which the circuit has been specially designed to handle. It will be recalled that the polarity signs at the opposite ends of the coil 56 are representative of circuit values for a negative gust condition.

The output from the first summing amplifier 58 which output appears at the terminals 60, 62 is fed through leads 90, 92 to a small ripple filter in the form of a capacitor 94 connected across said leads and a pair of resistors 96, 98. The ripple filter removes noise and high frequency or "hash" voltage fluctuations from the output of the amplifier 58 which are introduced by the standard 400 cycle frequency of its power supply. The resistor 96 is connected in the input leader 90 and the resistor 98 is an output lead 100 from the ripple filter.

The values for the capacitor 94 and resistors 96, 98 are such as to jointly present a small impedance and a fast time constant. In order to permit a rapid flow of current through the summing amplifier 58 the internal impedance of said amplifier is quite low, e.g., in the order of 50 ohms.

The output leads 100, 92 from the ripple filter are connected to opposite terminals of an integrating (storage) capacitor 102 which is designed to be charged by the output from the first summing amplifier. A resistor 104 is inserted in an output lead 106 from one terminal of the storage capacitor 102, the value of said resistor and said capacitor being so chosen that their RC time constant is comparatively prolonged, for example, about one minute.

An essentially unidirectional conducting device such as a diode 108 is interposed between the resistor 98 and a terminal of the storage capacitor. Said diode is so oriented that the storage capacitor can be charged only by a voltage at the output of the summing amplifier 58 which voltage is negative at the terminal 60 and positive at the terminal 62, suitable positive and negative symbols being provided in FIG. 1 to indicate this polarity condition.

By virtue of the foregoing arrangement the capacitor 102 will be charged when, and only when, the output from the summing amplifier is negative at the terminal 60 and positive at the terminal 62 and this condition will be found solely when there is a negative gust condition (i.e., a reduced air speed condition which is equivalent to an increased angle of attack condition and to a stall approaching condition), so that the upper end of the coil 56 is negative with respect to the lower end, and there either is no current i_2 flowing in the coil 64 or if the polarity at the upper end of the coil is positive with respect to the lower end due to an increase in average lift value over the null value, the value of the voltage across the coil 64 has an effect which is less than the effect of the value of the voltage across the coil 56. In other words, the storage capacitor 102 will charge only when the effect of a negative gust condition exceeds the effect of the average variation of the position of the lift vane 28 from null position.

The leads 110, 112 at the output of the integrating storage means which constitutes the storage capacitor 102 and the resistor 104 thus have impressed across them a bias voltage E_B that initially is a function of the first of a train of negative gusts and subsequently is a function of the stored memory of such initial negative gust or the degree to which subsequent negative gusts exceed the average increased lift condition E_L which has been brought about in response to an air speed command signal.

Said potential E_B across the leads 110, 112 is employed to bias an air speed command signal so as to call for increased air speed and for this purpose is fed into a suitable utilization device, for example, said potential can be fed into an input control coil of a speed command

computer 114 having output terminals connected to an air speed command (director) meter 116. Such a speed command computer is shown, for example, in my copending application Ser. No. 316,759, filed Oct. 16, 1963, for Airplane Instrument for Furnishing a Deceleration Modified Director Signal to Indicate or Control Corrective Action for Offsetting Decrease in Head Wind During Landing Approach, or in my Patent No. 3,043,540, issued July 10, 1962, for Airplane Instruments.

In the circuit illustrated in FIG. 1, I have illustrated a modified variation of the foregoing arrangement for utilizing the biasing signal E_B wherein the leads 110, 112 are connected to the input coil 118 of a second summing amplifier 120 of the same type as the summing amplifier 58. The summing amplifier has a second input coil 122 connected by leads 124, 126 to the output terminals of the speed command computer 114. The speed command computer impresses a potential E_{SC} on the input coil 122 that is a function of a command air speed, that is to say, if the airplane is going too slow for a given set of parameters, the current i_4 flowing through the coil 122 reflects this too slow condition. Such parameters are exclusive of the correction for negative gusts. The current i_3 flowing in the coil 118 is a function of the negative gust conditions. The currents i_3 and i_4 are summed in a cumulative sense for increasing air speed, so that if the potential appearing across the leads 124, 126 is indicative of a slow air speed condition and the potential appearing across the leads 110, 112 likewise is indicative of a slow air speed condition, the effects of the two coils 118, 122 will be added.

The summing amplifier 120 has a polarized output coil with output terminals 128, 130 connected to leads 132, 134 that run to a utilization mechanism such for example as an automatic throttle control or the air speed command meter 116. If the potential appearing across the leads 124, 126 is such as to indicate that the airplane is flying at a preselected desirable air speed for all parameters during landing approach except negative gusts and if the potential E_B appearing across the gusts leads 110, 112 is such as to call for an increased air speed, the potential appearing across the leads 132, 134 will call for (command) an increased air speed in the automatic throttle or the meter 116.

Alluding specifically to the meter 116, such a signal will swing the needle of said meter to the slow side of the null central position. When the pilot sees the meter in slow position he will increase his throttle setting so as to speed up the airplane and this will bring the needle back to the null position by virtue of the increased output from the speed command computer resulting from a faster signal issuing therefrom due to the increased lift input fed to said computer. This is the loop that will increase lift value as will be evidenced by an increase in the voltage E_L across the leads 78, 88.

The operation of the instrument 10 will now be described.

When the airplane is flying at a predetermined desirable average lift value, which value is to be maintained during landing approach and corresponds to a predetermined desirable landing approach average air speed, i_2 will be zero, or substantially so, inasmuch as the position assumed by the vane 28 will correspond to the setting of the wiper 70. If at this time there are no negative gusts the current i_1 will be zero. The storage capacitor 102 will not be charged so that the current i_3 will be zero. The current i_4 , if the speed command computer is a nulled instrument, will also be zero and the meter 116 will have its needle in null position, or the automatic throttle will be at a setting which maintains the desired average air speed and average lift condition.

Now assume that a negative (tail wind) gust develops. i_2 will not change immediately because of the time constant of the capacitor 82 and resistors 84, 86 which is several, e.g., about five seconds. However, i_1 immediately

starts to flow in the negative sense indicated by the polarity signs associated with the coil 56. This direction of flow signals a speed that is too slow, which is equivalent to directing a pilot to increase speed. Said signal will be passed by the summing amplifier 58 without any modification from the coil 64 (because i_2 still is zero or is only slowly starting to flow) and will quickly charge up the storage capacitor 102 inasmuch as the time constant of the capacitor 94 and the resistors 96, 98 is very small. The potential from the capacitor 102 will cause a flow of current i_3 in the coil 118 in a direction to deflect the needle of the meter 116 to the slow side.

Such indication in the meter or any other utilization mechanism employed will take place immediately upon the occurrence of the first negative gust. The pilot will advance the throttle setting to increase the air speed of the airplane so as to counter the effect of this first negative gust.

The time constant of the storage capacitor 102 and associated resistor 104 is quite lengthy, for example, about a minute. Hence, it takes this period of time for its charge to be materially reduced and over this period the gust bias influence on the command signal will indicate that the air speed is to be increased. Subsequent negative gusts tend to keep the capacitor 102 charged.

As a result of the command to the pilot or to the automatic throttle control to increase air speed, the setting of the vane 28 will be changed to correspond to the increased average lift value. This will cause the current i_2 to flow in the coil 64 in the direction indicated by the polarity signals associated with that coil. Such a signal indicates an increased average lift value or air speed and hence opposes the signal caused by the flow of the current i_1 in the direction indicated in the circuit. If the effect of the signal i_2 exceeds that of the signal i_1 no further charge will be impressed on the capacitor 102 due to the presence of the diode 108 which only permits charging of the capacitor 102 in a certain direction corresponding to a negative gust and does not permit discharge thereof in the opposite direction from the input side of such storage capacitor. Thus, the combination of the diode 108 and the coil 64 acts as a clamping means to clamp the charging of the storage capacitor 102 at a variable clamping level which is a function of average lift condition, this being manifested in the circuit of FIG. 1 as an average lift value sensed by the lift vane 28. Thereby an equilibrium condition will be reached as to average air speed, lift value and angle of attack which will be unaffected by further gusts unless the gusts are of a greater value than the initial gusts or unless the further gusts occur after the charge on the storage capacitor 102 has decayed and the average lift condition of the airplane has been reduced to match this decayed value.

After a train of negative gusts has ceased and, a few minutes later when the capacitor 102 has substantially fully discharged, the current i_3 in the second summing amplifier 122 will reduce to zero and the original operating parameters will be restored. In a continual uniform negative gusting air mass balance conditions will be reached when the current i_1 is just enough greater (more negative) than the clamping current i_2 to keep the storage capacitor 102 charged to a level which will yield an i_3 current sufficient to make the airplane fly enough faster to keep the i_2 current at the required value to result in such a balance.

It thus will be appreciated that the instrument 10 operates in a manner such as to provide several desirable features. The initial negative gust will immediately command a higher airplane air speed. By following the command an increased air speed is maintained as long as required, that is to say, as long as subsequent negative gusts continue to occur. The air speed, however, upon following the command is slowly reduced as conditions permit without objectionable rapid fluctuating changes in speed command. The variable clamping level sub-

stantially eliminates fluctuating speed commands once a safe average lift condition has been reached. The response of the bias signal appearing across the leads 110, 112 is essentially unidirectional so that the potential applied to the input coil 118 can only command an increase and not a decrease of air speed; thus the circuit does not respond to positive gusts and therefore no reduction in air speed will be commanded as a result of such bias signal.

As indicated previously, the rate of change of air speed as evinced by the voltage E_{RCAS} , which is a function of the amplitude of negative gusts, is balanced for clamping purposes against an average lift condition which is evinced in FIG. 1 as a voltage E_L . Lift condition can be sensed by the prevailing lift value of the airplane or, alternately, by equivalent parameters such for instance as the prevailing air speed or the prevailing angle of attack. In FIG. 2 I have shown an instrument 10' which is the same as the instrument 10 except that for the lift sensor 14 I have substituted an air speed sensor. Inasmuch as an air speed sensor is necessary to derive a voltage that is a function of the rate of change of air speed, the same air speed sensor is employed for both purposes.

Specifically I provide an air speed sensor 136 having a physical construction identical to that of the air speed sensor 12. It includes a case 138 the interior of which is connected to prevailing ambient static pressure by a tube 140. Within the interior of the case is a bellows 142 the inside of which is connected by a tube 144 to a forwardly facing Pitot head in a region where it is minimally influenced by disturbing factors. The wall 146 of the bellows, the position of which varies as a function of the difference of the pressures externally and internally of the bellows, drives two wipers 148, 150 which are mutually electrically insulated. The remainder of the instrument 10' is the same as the remainder of the instrument 10 already described in detail. Thus, the wiper 148 rides on the potentiometer winding 74 and the wiper 150 rides on the potentiometer winding 44. The other elements of the circuit for the instrument 10' up to the bias signal leads 110, 112 have been shown in FIG. 2 and have had reference numerals applied thereto which are the same as those for corresponding elements of FIG. 1. Since all the other parts of the instrument 10' are the same as those of the instrument 10 they have not been shown. It will be observed that the output from the potentiometer 74 is damped to obtain a voltage E_{AS} that is a function of average air speed rather than of air speed as instantaneously affected by gusts.

In FIG. 3 I have illustrated an instrument 10'' which is identical to the instrument 10 shown in FIG. 1 except for the means to drive the wiper 76. Since all other parts of the instrument 10'' are the same as those of the instrument 10, they have not been shown. The instrument 10'' senses lift condition by measuring angle of attack. For this purpose I employ an angle of attack sensor 152 constituting an angle of attack vane 154 affixed to an arm 156 that turns about a lateral shaft 158, to wit, a shaft perpendicular to the line of flight A and horizontal when the airplane is in level flight. The arm 156 drives the wiper 76 of the potentiometer having the fixed winding 74 and through a damping RC network controls the current i_2 flowing in the coil 64 as a function of average angle of attack.

As I have mentioned earlier, it is not essential to the construction of an instrument embodying my present invention that the value of the rate of change of air speed engendered by gusts be taken from a first means that includes a means which directly senses and, therefore, directly measures air speed and from it computes rate of change of air speed. An equally satisfactory equivalent result will be obtained if the first means is subdivided into sundry subordinate sensing means and a computing means, the sensing means being capable of measuring values from which air speed can be computed and the computing

means being capable of performing calculations, including differentiation, upon said values so as to derive the rate of change of air speed. The thus obtained rate of change of air speed is the equivalent of the rate of change of air speed obtained by directly measuring air speed and differentiating such measurement, and can be substituted for it.

In FIG. 4 I have shown an instrument 10'' which is identical to the instrument 10 except for an altered construction of the first means to supply the current i_1 which is a function of the gust engendered rate of change of air speed (gust engendered fluctuations in air speed). Since all other parts of the instrument 10'' are the same as those of the instrument 10 they have not been shown.

The instrument 10''' measures gust engendered rate of change of air speed by measuring vertical acceleration and lift value and from the changes thereof, by differentiation and calculation, obtaining rate of change of air speed.

Specifically, in FIG. 4 I have illustrated only so much of the instrument 10''' as supplies the current i_1 to the input control coil 56 of the summing amplifier 58. The components and connections of the circuit that supplies the current i_2 to the input coil 64 are the same as in FIG. 1 and, therefore, have been omitted. For the same reason the components and connections of the circuit leading from the output terminals 60, 62 via leads 90, 92 have been omitted.

The instrument 10''' includes two sensors in the first means, to wit, a vertical, i.e., normal, accelerometer 160 and a lift sensor 162 both of which are conventional.

The vertical accelerometer comprises a weight 164 constrained in guides (not shown) to permit movement only along the Z-axis of the airplane which is perpendicular to the plane containing the X-axis (the longitudinal axis of the fuselage) and the Y-axis (the longitudinal axis of the wing span). The weight is supported by a counterbalancing, i.e., centering, compression spring 166. The weight 164 drives a movable wiper 168 of a potentiometer 170 having a fixed winding 172 connected across a suitable DC source such as a battery 174. The voltage E_{VA} between a lead 176 from the wiper 168 and a lead 178 from one end of the potentiometer is a function of the vertical acceleration of the airplane. A differentiating capacitor 180 series inserted in the lead 178 converts the voltage E_{VA} to a voltage E_{RCVA} which is a function of the rate of change of vertical acceleration and which is present across the lead 176 and a lead 182 extending from the capacitor 180.

The lift sensor 162 is identical to the lift sensor 14. Alternatively it may be identical to the angle of attack sensor 152. Said sensor 162 comprises a vane 184 which extends through a slot 186 in a mounting plate 188 that is secured over an opening 190 in the skin of the wing adjacent the nose (leading edge) thereof. Located behind the skin of the wing is a transversely (spanwise) extending pivot 192 for the vane which is so positioned that it is behind the center of pressure of the vane. Suitable means, such for instance, as a pair of opposed springs 194, 196, are provided to bias the vane to an equilibrium position between stops. Said vane is so located at the nose of the airplane that it is subjected to variation in pressure caused by shifting of the stagnation point over the nose of the wing. The particular location of the vane on the nose and the strength of the springs 194, 196 are not critical for proper performance of the instrument 10'''. The angular position assumed by the vane 184 is a measure of the prevailing lift value. In the event the sensor 162 is constructed like the sensor 152 the angular position of the vane will be a measure of the prevailing angle of attack.

The vane 184 drives a movable wiper 198 of a potentiometer 200 having a fixed winding 202 connected across a suitable DC source such as a battery 204. A potentiometer 206 has its fixed winding 208 connected in shunt with the winding 202 so that the two potentiometers form

a resistance bridge for which the battery 204 supplies the input. The bridge output appears across the lead 210 running from the wiper 198 and the lead 212 running from the wiper 214 for the potentiometer 206.

The position of the wiper 214 establishes a null point for the output on the leads 210, 212, that is to say, with a predetermined position of the wiper 214 in a certain position of the wiper 198 the output on the leads 210, 212 will be zero. At any position of the lift vane 184 indicating a higher lift value than the null value corresponding to the position of the wiper 214, the lead 210 becomes negative with respect to the lead 212 and vice versa. The wiper 214 is set either manually or automatically for any pre-selected desirable lift value, for example, a lift value corresponding to an air speed which is safely above, by a desirable amount, the minimum air speed during landing approach. If the lift value increases, as with an increase in air speed, above the null value the lead 210 will go negative with respect to the lead 212 by an amount which is a function of the value of lift in excess of the set null value represented by the set position of the wiper 214.

In order to establish a proper proportion between the outputs from the vertical accelerometer and the lift sensor at least one such output, e.g., the output from the lift sensor 162, is arranged to be adjustable with respect to the other output. For this purpose the leads 210, 212 are connected to the ends of a fixed winding 215 of a potentiometer 216 having a wiper 218. The voltage E_L appearing between the lead 220 running from the wiper 218 and the lead 222 running from an end of the potentiometer winding 215 is a function of the lift value of the airplane having an amplitude range that can be adjusted by varying the position of the wiper 218. A differentiating capacitor 224 series inserted in the lead 222 converts the voltage E_L to a voltage E_{RCL} which is a function of the rate of change of lift value and which is present across the lead 220 and a lead 226 extending from the capacitor 224.

A computer 230 combines the outputs E_{RCVA} and E_{RCL} and supplies its own output voltage E_{RCAS} that is a function of the rate of change of air speed and that appears across the output leads 232, 234. Because the computer is only required to operate within a narrow range of outputs which represent gust engendered variations to a predetermined landing approach air speed, it can be of simple construction and may, as shown, be in the form of a summing bridge. Three legs of the bridge constitute resistances 236, 238 and 240 while the fourth leg constitutes the input control coil 56 of the summing amplifier 58. The voltage E_{RCVA} is applied across the junction 242 between the resistor 236 and the coil 56 and the junction 244 between the resistors 238 and 240. The voltage E_{RCL} is applied across the junction 246 between the resistors 236 and 238 and the junction 248 between the resistor 240 and the coil 56.

It will be apparent from the foregoing that the outputs from the vertical accelerometer and the lift vane (or angle of attack vane) are separately fed to different capacitors 180, 224. The capacitors pass fluctuating (rate of change) currents to the summing bridge 230 which, in turn, feeds the current i_1 into the input coil 56 of the summing amplifier 58.

The output adjustment potentiometer 216 has its wiper 218 set so that the fluctuations of i_1 will be responsive to fluctuations of the air speed. This may be accomplished by adjusting the position of the wiper 218 so that signal changes from the vertical accelerometer are substantially cancelled by signal changes from the lift sensor at an essentially fixed air speed. Thereby any unbalancing causing a flow of current i_1 will be a measure of gust engendered fluctuations in air speed.

The sources of voltage are so polarized and the directions of movements of the wipers 168, 198 responsive to change in prevailing air speed are such that upon a decrease in air speed the terminal of the coil 56 which is connected to the junction 242 will be negative with respect

to the other terminal of said coil as indicated in FIG. 4. At a constant air speed the voltage E_{RCAS} will be zero.

Although I have shown the outputs E_{VA} and E_L from the vertical accelerometer and lift sensor as being differentiated to yield voltages E_{RCVA} and E_{RCL} before being combined to calculate and furnish the voltage E_{RCAS} , it is to be understood that said outputs E_{VA} and E_L can also be combined without differentiations in a computer such as the computer 230 to calculate and yield at the computer output a voltage E_{AS} which is a function of the air speed of the airplane and that this later voltage E_{AS} can be differentiated to yield the voltage E_{RCAS} that is fed to the input coil 56. Such an alternative circuit arrangement for the first means is the same as that shown in full lines in FIG. 4 except that the capacitors 180 and 224 are omitted and, instead, a differentiating capacitor 250 (shown in dotted lines in FIG. 4) is series inserted in the lead between the junction 242 and the upper terminal of the input.

The operation of the instruments 10', 10'' and 10''' illustrated in FIGS. 2, 3 and 4 are identical to the operation of the instrument 10 already described in detail.

It thus will be seen that I have provided devices which achieve the several objects of my invention and which are well adapted to meet the conditions of practical use.

As various possible embodiments might be made of the above invention, and as various changes might be made in the embodiments set forth, it is to be understood that all matter herein described or shown in the accompanying drawings is to be interpreted as illustrative and not in a limiting sense.

Having thus described my invention, I claim as new and desire to secure by Letters Patent:

1. For use in an airplane instrument that controls the air speed of an airplane during landing approach, means to furnish a bias signal to command an increase in air speed to offset the effect of negative gusts on air speed during landing approach, said means comprising a first means having an output which is responsive to gust engendered fluctuations in air speed, a second means having an output which is a function of the difference between the prevailing average lift condition of the airplane and a predetermined desirable null lift condition, the outputs of the first and second means being in the same negative sense for decreasing air speed, a third means for comparing the outputs of the first and second means and furnishing a difference output, and an integrator responsive to and for storing substantially only a negative output of the third means as said bias signal, such negative output corresponding to an approach to stall.

2. A bias signal furnishing means as set forth in claim 1 wherein the second means has an output which is a function of the difference between the prevailing average air speed of the airplane and a predetermined desirable null air speed.

3. A bias signal furnishing means as set forth in claim 1 wherein the second means has an output which is a function of the difference between the prevailing average angle of attack of the airplane and a predetermined desirable null angle of attack.

4. A bias signal furnishing means as set forth in claim 1 wherein the first means includes a sensor that is directly responsive to air speed.

5. A bias signal furnishing means as set forth in claim 4 wherein the first means also includes means differentiating the signal from the air speed sensor.

6. A bias signal furnishing means as set forth in claim 1 wherein the first means includes a vertical accelerometer, a lift sensor and a computer to which are fed the signals from the vertical accelerometer and the lift sensor to calculate air speed therefrom.

7. A bias signal furnishing means as set forth in claim 6 wherein the first means also includes a differentiating means.

8. A bias signal furnishing means as set forth in claim

6 wherein the first means also includes means to differentiate the signals from the vertical accelerometer and the lift sensor before they are fed to the computer.

9. A bias signal furnishing means as set forth in claim 6 wherein the first means also includes means to differentiate the output from the computer.

10. A bias signal furnishing means as set forth in claim 1 wherein the first means includes a vertical accelerometer, a null lift vane, and a computer to which are fed the signals from the vertical accelerometer and the null lift vane to calculate air speed therefrom.

11. A bias signal furnishing means as set forth in claim 1 wherein the first and second means include physical sensors and electric transducers to convert changes in condition of the physical sensors into variable electrical characteristics and wherein the third means and the integrator are electrical.

12. A bias signal furnishing means as set forth in claim 11 wherein all the outputs are voltages.

13. A bias signal furnishing means as set forth in claim 11 wherein a unidirectional conducting device is interposed between the third means and the integrator and is oriented to conduct the output from the third means to the integrator only when the output from the first means responsive to a negative gust condition exceeds the output from the second means responsive to an increased average lift condition.

14. A bias signal furnishing means as set forth in claim 13 wherein the integrator has a prolonged time constant.

15. A bias signal furnishing means as set forth in claim 14 wherein the time constant of the integrator is about one minute.

16. A bias signal furnishing means as set forth in claim 14 wherein the second means has a time constant of a few seconds.

17. A bias signal furnishing means as set forth in claim 13 wherein a speed command computer also is provided and wherein the bias signal is connected to an input of the speed command computer.

18. A bias signal furnishing means as set forth in claim 13 wherein there also are provided a speed command computer with an output, a summing means with plural inputs and an output, and a utilization mechanism with an input, the output of said speed command computer and the output of the integrator being connected to the inputs of the summing means, and the output of the summing means being connected to the input of the utilization mechanism.

19. A bias signal furnishing means as set forth in claim 13 wherein the third means is a summing means having plural inputs, one connected to the output of the first means and the other to the output of the second means, the inputs of the summing means being cumulative.

20. A bias signal furnishing means as set forth in claim 13 wherein the integrator includes a capacitor.

21. A bias signal furnishing means as set forth in claim 13 wherein the integrator is an RC network with a prolonged time constant.

22. A bias signal furnishing means as set forth in claim 13 wherein the first means includes a sensor providing a voltage responsive to air speed and a series connected capacitor to differentiate said voltage to a voltage which is a function of the rate of change of air speed.

23. For use in an airplane instrument that controls the air speed of an airplane during landing approach, means to furnish a bias signal to command an increase in air speed to offset the effect of negative gusts on air speed during landing approach, said means comprising a first means having an output which is responsive to gust engendered fluctuations in air speed, a second means having an output which is a function of the difference between the prevailing average lift condition of the airplane and a predetermined desirable null lift condition, the outputs of the first and second means being in the same sense for increasing air speed, a third means for

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comparing the outputs of the first and second means and furnishing a difference output, and an integrator responsive to and for storing as said bias signal substantially only an output of the third means corresponding to a reduced air speed condition.

24. For use in an airplane instrument that controls the air speed of an airplane during landing approach, means to furnish a bias signal to command an increase in air speed during landing approach, said means comprising a first means having an output which is responsive to gust engendered fluctuations in air speed, a second means having an output which is a function of the difference between the prevailing average lift condition of the airplane and a predetermined desirable null lift condition, the outputs of the first and second means being in the same sense for increasing air speed, a third means for comparing the outputs of the first and second means and furnishing a difference output, and an integrator responsive to and for storing as said bias signal substantially only an output of the third means corresponding to an increased angle of attack condition.

25. For use in an airplane instrument that controls the air speed of an airplane during landing approach, means to furnish a bias signal to command an increase in air speed to offset the effect of negative gusts on air speed

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during landing approach, said means comprising a first means having an output which is responsive to gust engendered fluctuations in air speed, a second means having an output which is a function of the difference between the prevailing average lift condition of the airplane and a predetermined desirable null lift condition, the outputs of the first and second means being in the same sense for increasing air speed, a third means for comparing the outputs of the first and second means and furnishing a difference output, and an integrator responsive to and for storing as said bias signal substantially only an output of the third means corresponding to a stall approaching condition.

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