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# United States Patent [19]

**Rutan et al.**

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[45] **Date of Patent: Jun. 23, 1998**

[54] **ACTIVE FEEDBACK LOOP TO CONTROL BODY PITCH IN STOL/VTOL FREE WING AIRCRAFT**

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[73] Assignee: **Freewing Aerial Robotics Corporation**, College Park, Md.

[21] Appl. No.: **468,420**

[22] Filed: **Jun. 6, 1995**

**Related U.S. Application Data**

[63] Continuation-in-part of Ser. No. 332,321, Oct. 31, 1994, abandoned, which is a continuation of Ser. No. 7,130, Jan. 22, 1993, Pat. No. 5,395,073.

[51] **Int. Cl.**$^6$ .................................................... **B64C 13/16**

[52] **U.S. Cl.** ......................... **244/76 R**; 244/48; 244/7 B; 244/81; 244/120

[58] **Field of Search** ................................. 244/120, 76 R, 244/12.1, 6, 7 R, 56, 48, 76 B, 182, 181, 199, 195, 7 B, 82

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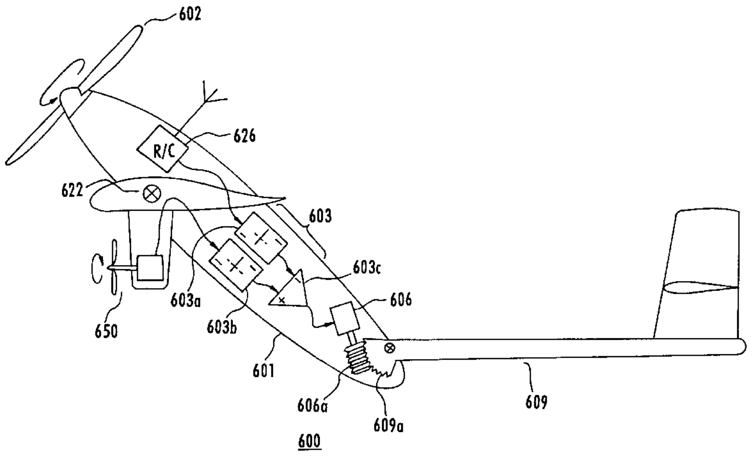
*Attorney, Agent, or Firm*—Lowe Hauptman; Gopstein & Berner

[57] **ABSTRACT**

An aircraft control system for controlling an aircraft, particularly a free wing aircraft in low speed or hover regimes. An air speed sensor measures air speed of the aircraft and outputs an air speed signal to a control processor which processes the air speed signal with a speed control input signal. A control actuator actuates an aircraft control surface in response to the control surface control signal. The air speed sensor may include a shaft mounted impeller located in an airstream of the aircraft. A rotational speed sensor, coupled to the impeller, measures a rotational speed of the impeller and outputs a rotational speed signal as the air speed signal. In an alternative embodiment, the air speed sensor may include a vane located in an airstream of the aircraft and deflected in response to air flow in the airstream. In another embodiment, the speed sensor may include an angular position sensor which measures an angle between a free wing and the aircraft fuselage and outputs an angle measurement signal as the air speed signal. The aircraft control surface may comprises a control boom pivotally attached to a fuselage of the aircraft of a trim tab pivotally attached to a fuselage of the aircraft.

**3 Claims, 12 Drawing Sheets**



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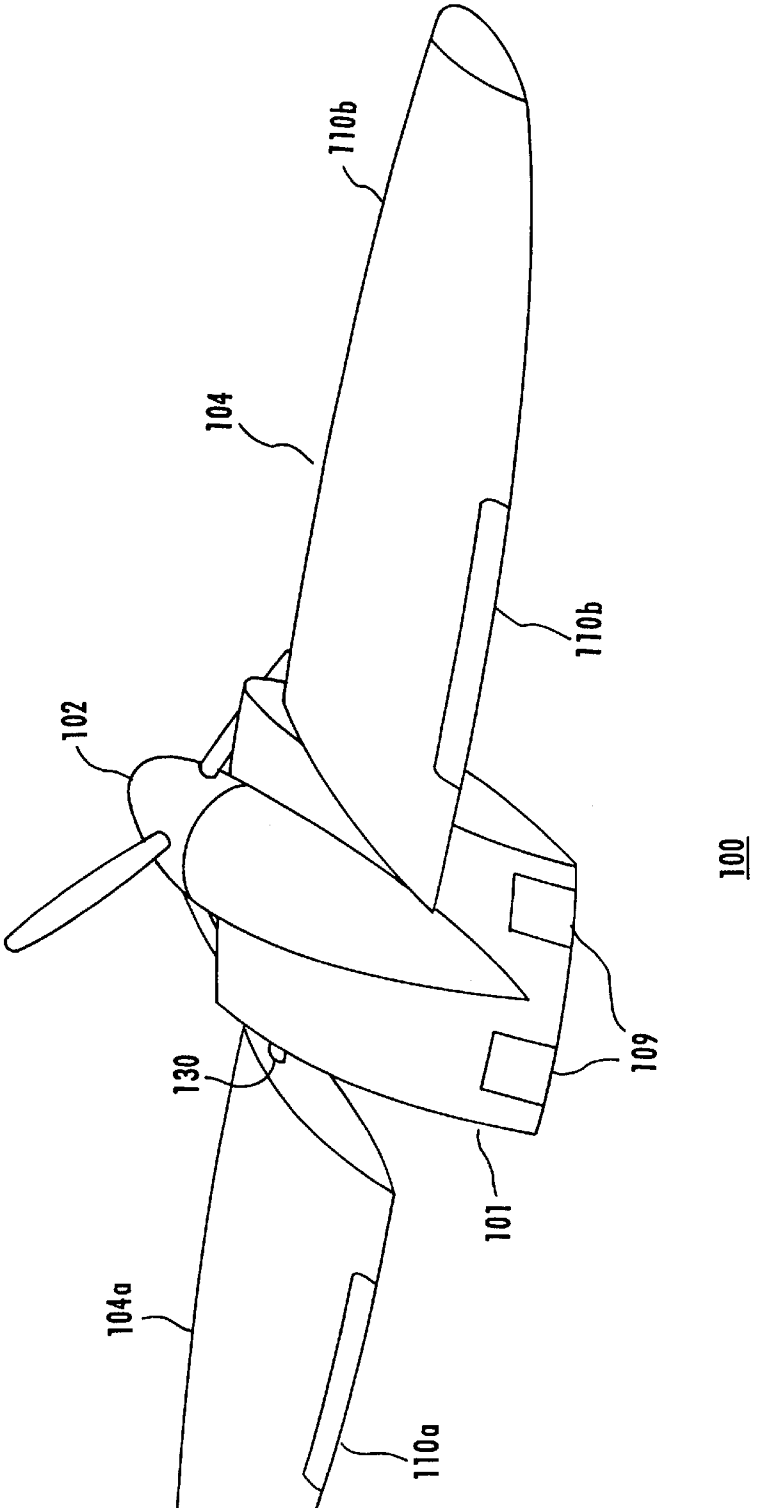


Fig. 1

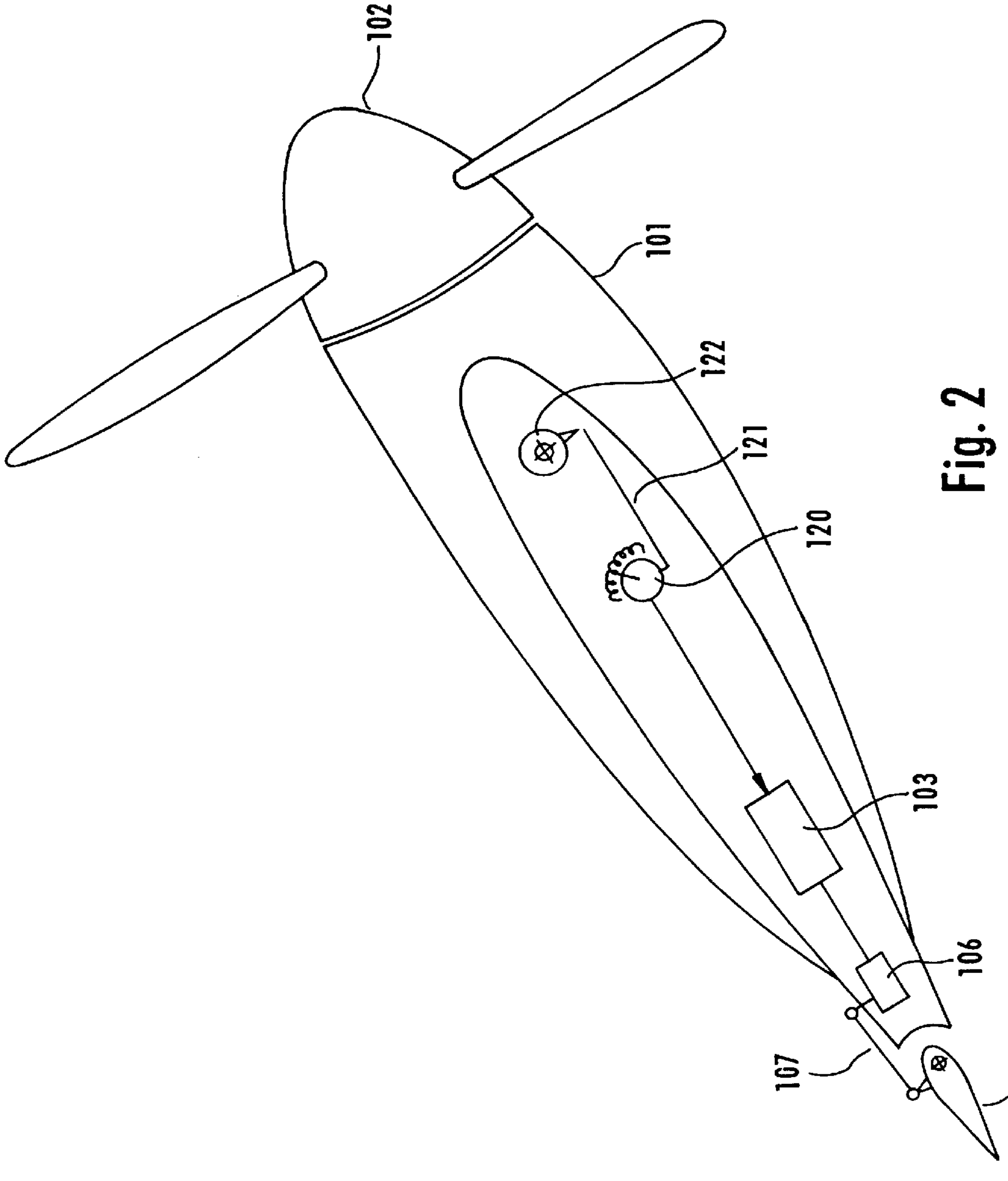


Fig. 2

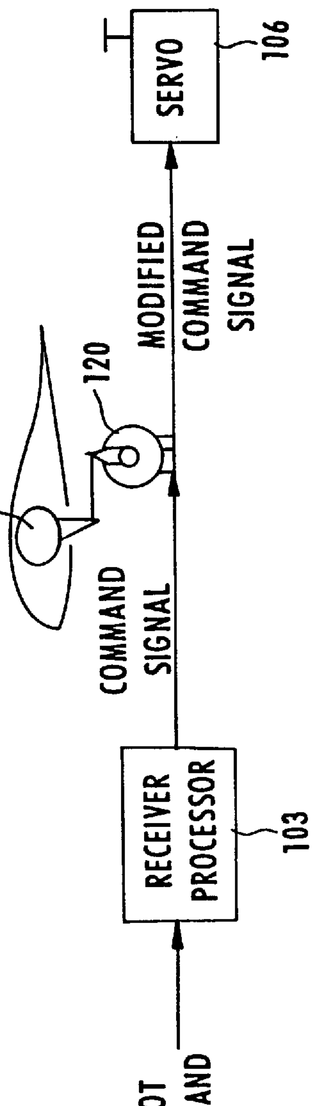

PILOT COMMAND
RECEIVER PROCESSOR
103
COMMAND SIGNAL
122
120
MODIFIED COMMAND SIGNAL
SERVO
106

Fig. 3

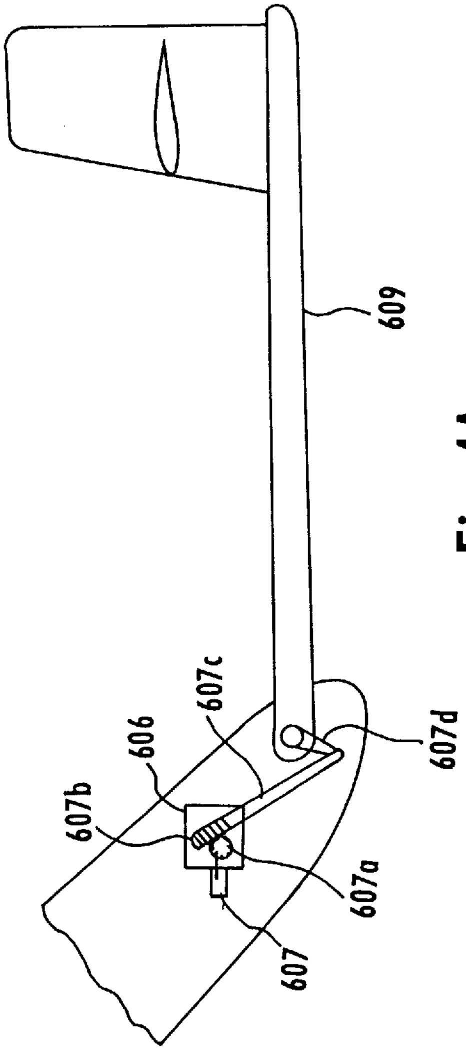

609
607c
606
607b
607a
607
607d

Fig. 4A

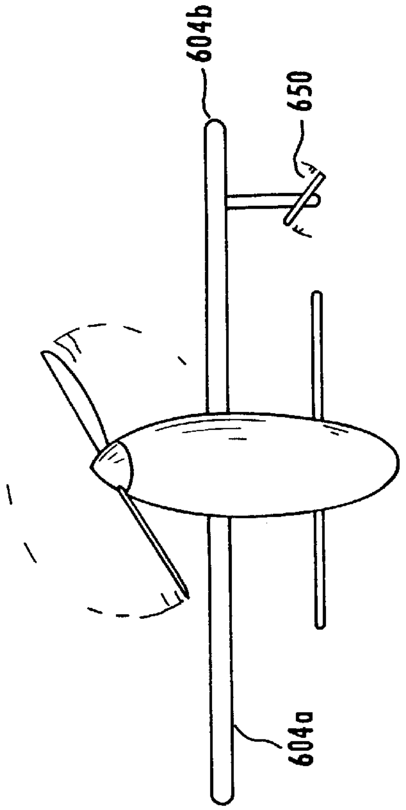

604b
650
604a

Fig. 5

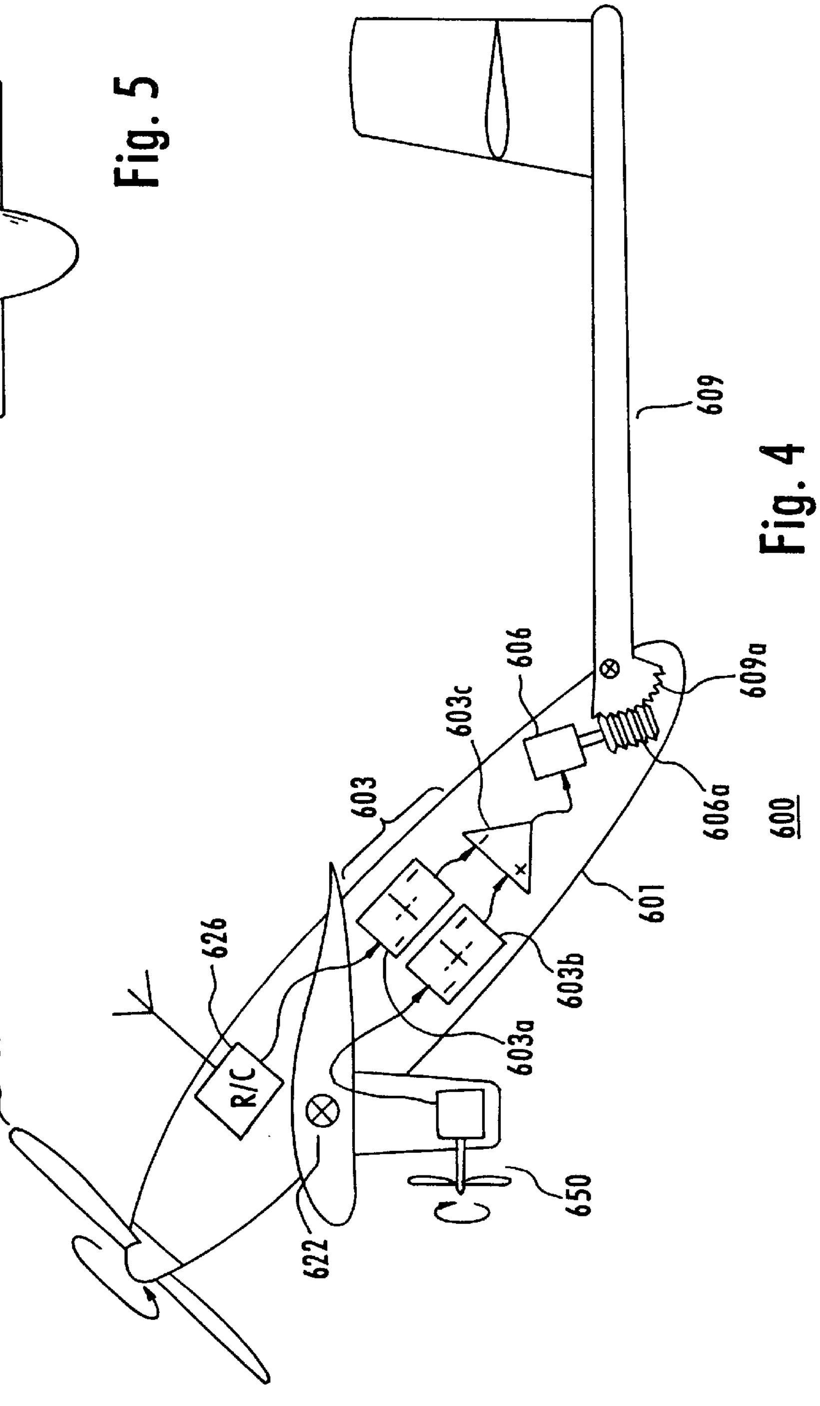

602
626
R/C
622
650
603a
603b
603
603c
606
606a
609a
601
600
609

Fig. 4

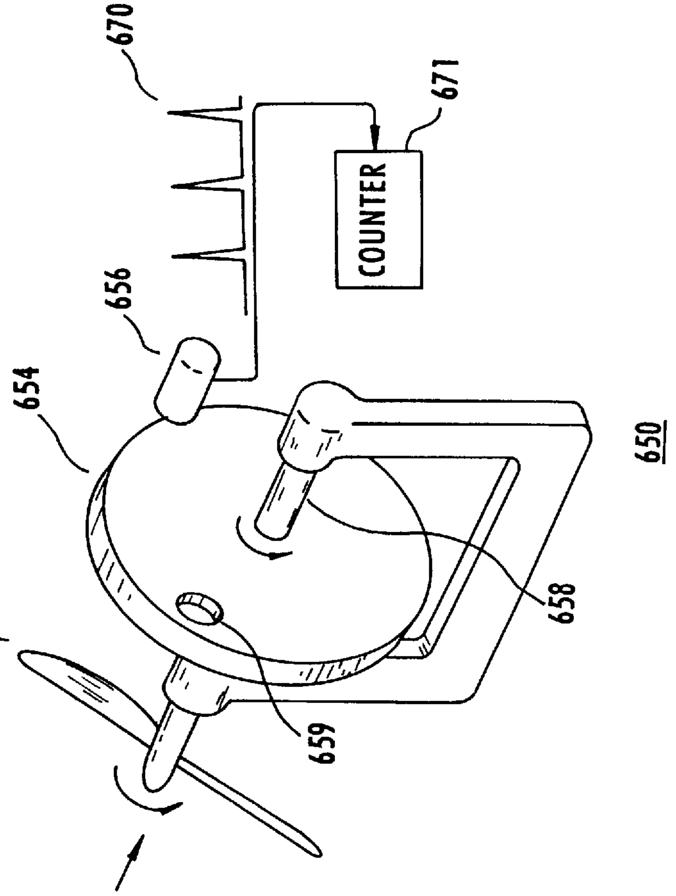

670
671
COUNTER
656
654
652
658
659
650

Fig. 6

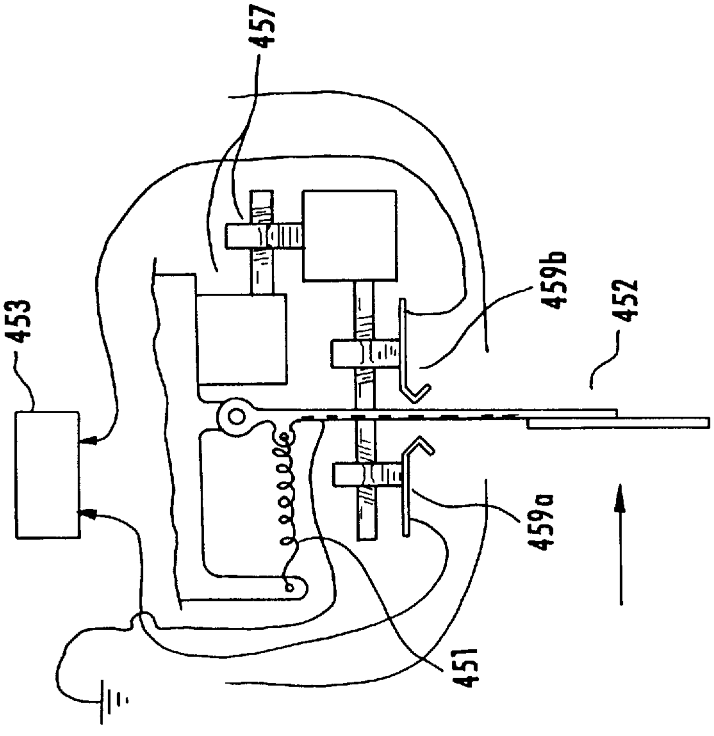

457
453
459b
452
459a
451

Fig. 7

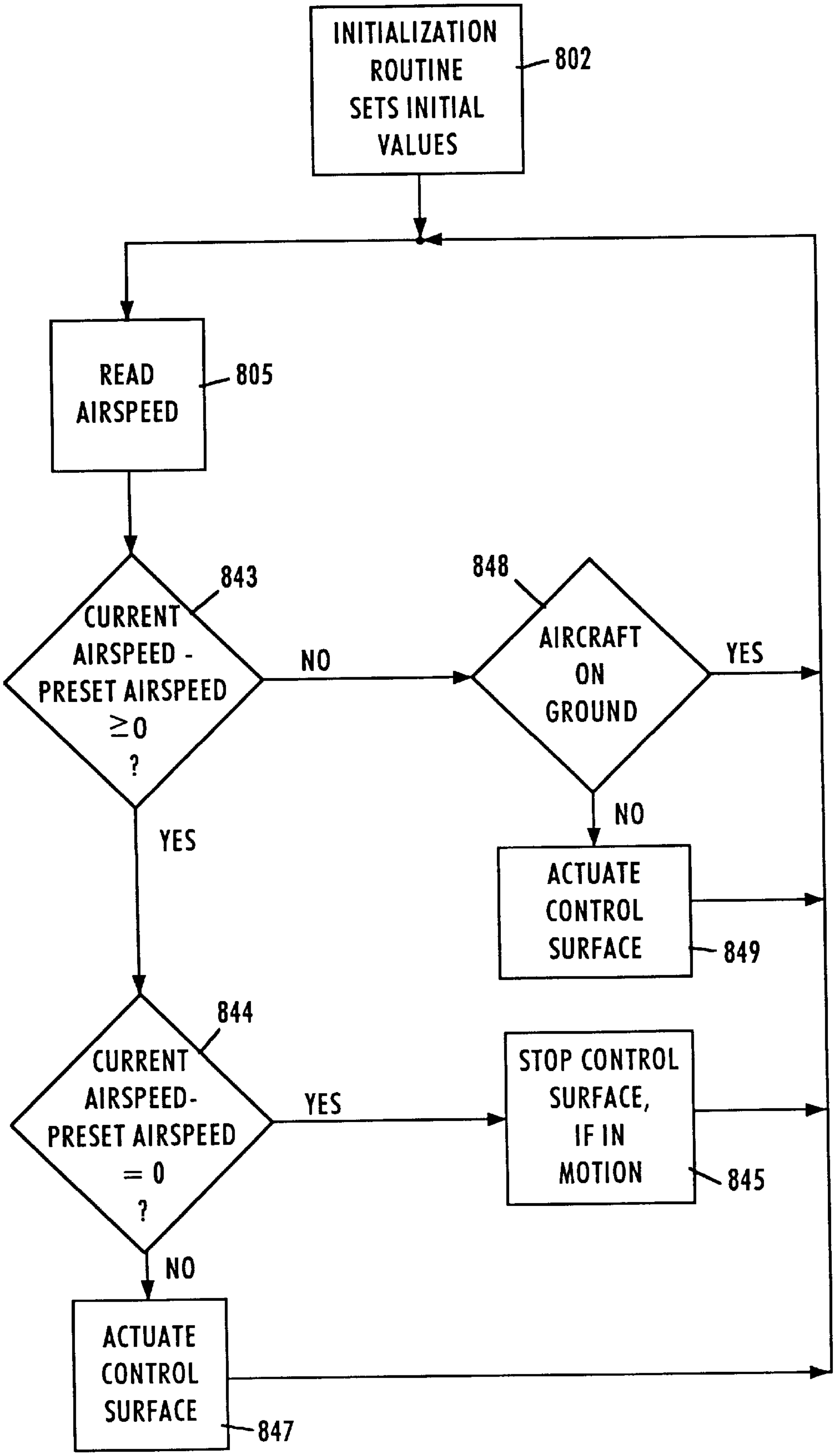
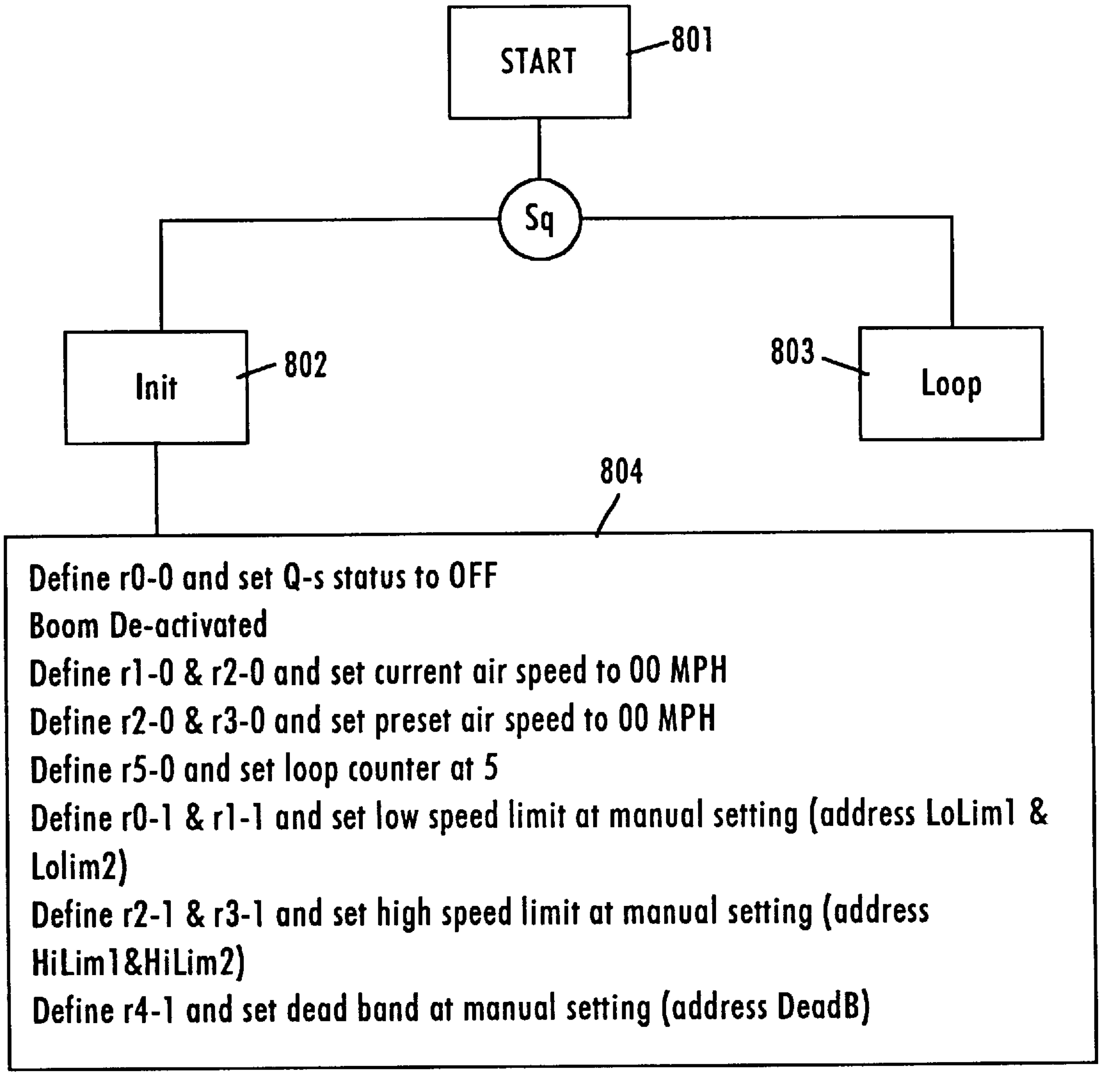

INITIALIZATION ROUTINE SETS INITIAL VALUES
802
READ AIRSPEED
805
CURRENT AIRSPEED - PRESET AIRSPEED ≥0 ?
843
NO
848
AIRCRAFT ON GROUND
YES
NO
ACTUATE CONTROL SURFACE
849
YES
CURRENT AIRSPEED- PRESET AIRSPEED = 0 ?
844
YES
STOP CONTROL SURFACE, IF IN MOTION
845
NO
ACTUATE CONTROL SURFACE
847

Fig. 8



Define r0-0 and set Q-s status to OFF
Boom De-activated
Define r1-0 & r2-0 and set current air speed to 00 MPH
Define r2-0 & r3-0 and set preset air speed to 00 MPH
Define r5-0 and set loop counter at 5
Define r0-1 & r1-1 and set low speed limit at manual setting (address LoLim1 & Lolim2)
Define r2-1 & r3-1 and set high speed limit at manual setting (address HiLim1&HiLim2)
Define r4-1 and set dead band at manual setting (address DeadB)

Fig. 8A

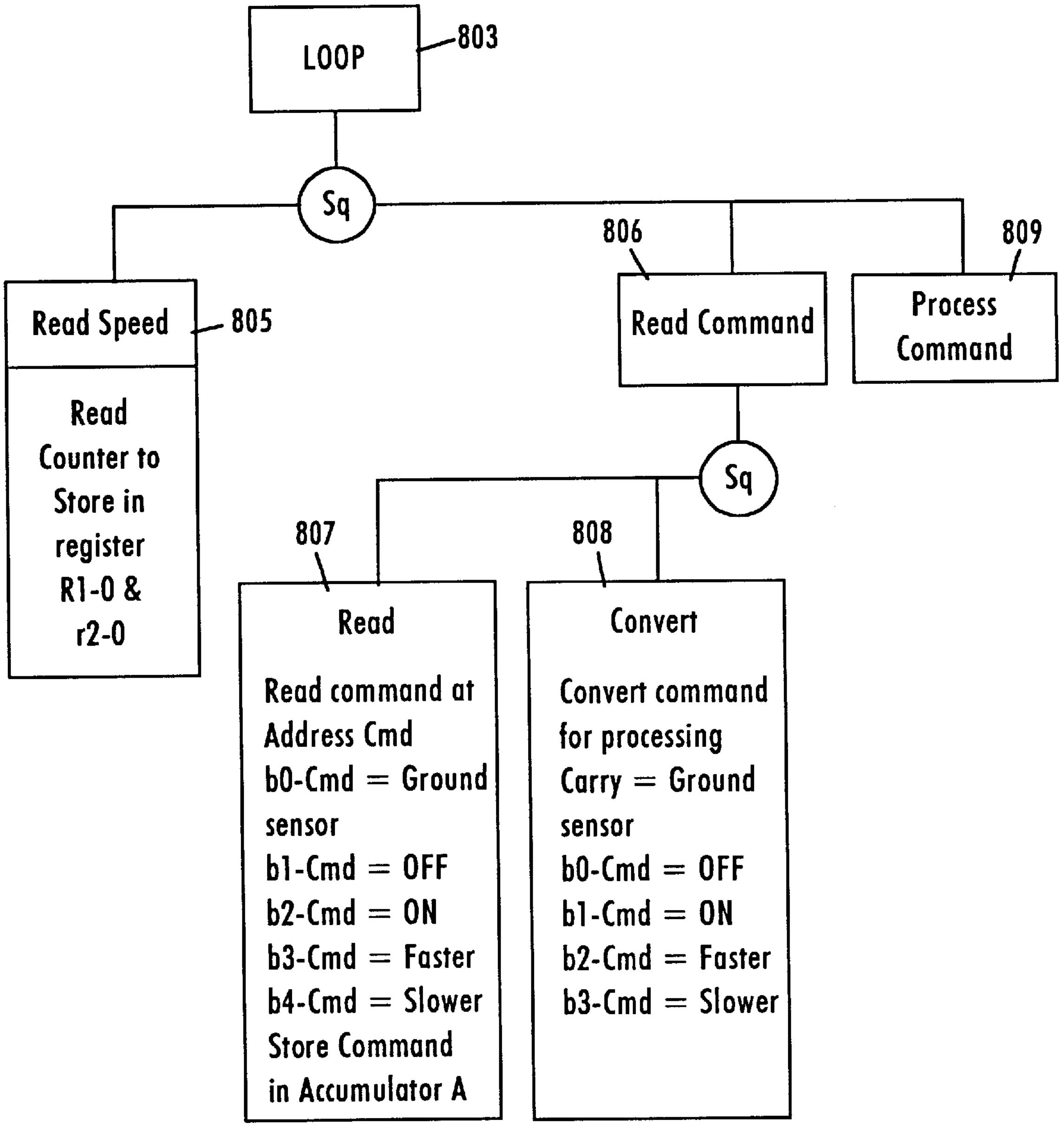

LOOP
803
Sq
Read Speed
805
Read Counter to Store in register R1-0 & r2-0
806
Read Command
809
Process Command
Sq
807
Read
Read command at Address Cmd
b0-Cmd = Ground sensor
b1-Cmd = OFF
b2-Cmd = ON
b3-Cmd = Faster
b4-Cmd = Slower
Store Command in Accumulator A
808
Convert
Convert command for processing
Carry = Ground sensor
b0-Cmd = OFF
b1-Cmd = ON
b2-Cmd = Faster
b3-Cmd = Slower

Fig. 8B

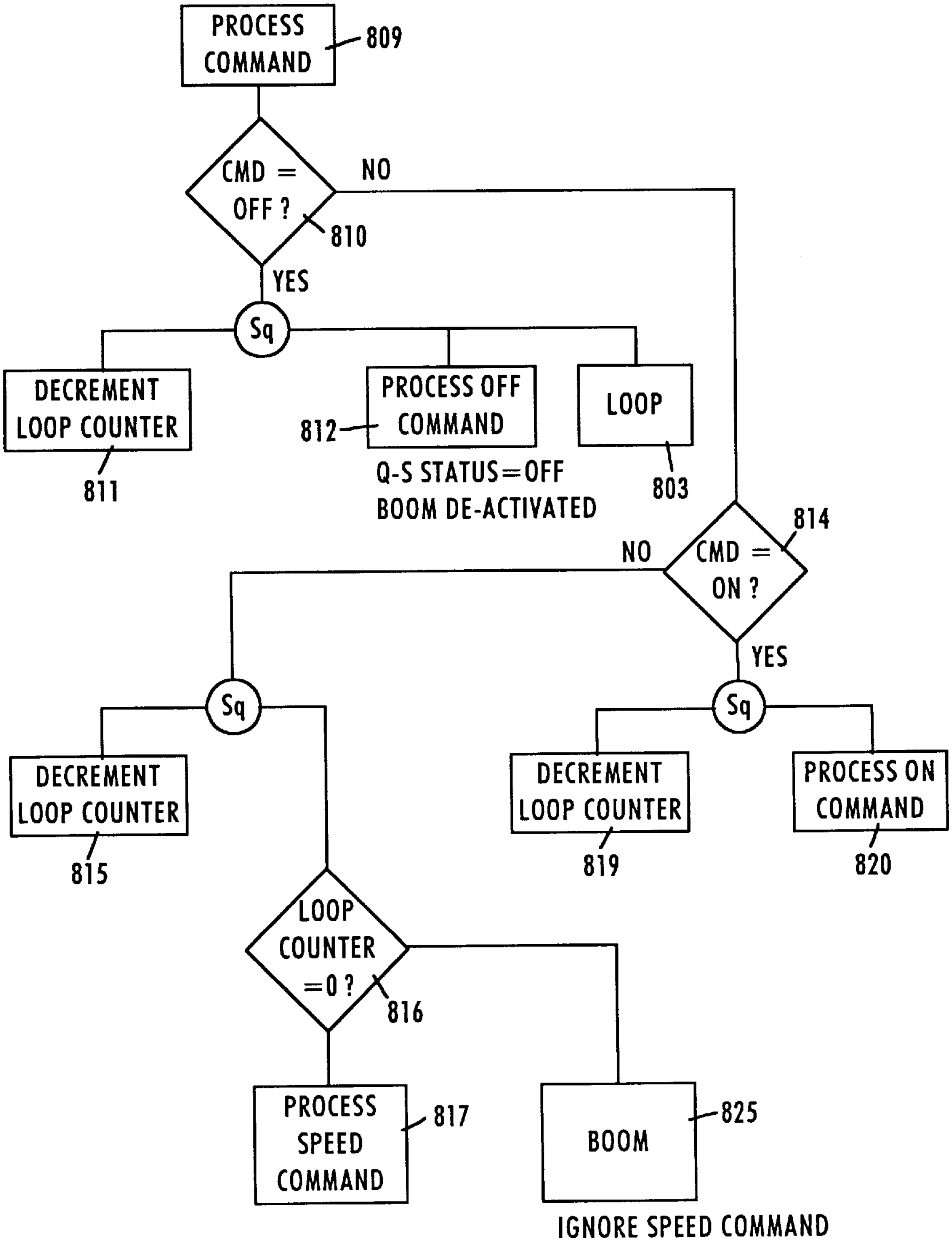

PROCESS COMMAND
809
CMD = OFF ?
810
NO
YES
Sq
DECREMENT LOOP COUNTER
811
PROCESS OFF COMMAND
812
Q-S STATUS=OFF
BOOM DE-ACTIVATED
LOOP
803
CMD = ON ?
814
NO
YES
Sq
DECREMENT LOOP COUNTER
815
Sq
DECREMENT LOOP COUNTER
819
PROCESS ON COMMAND
820
LOOP COUNTER =0 ?
816
PROCESS SPEED COMMAND
817
BOOM
825
IGNORE SPEED COMMAND

Fig. 8C

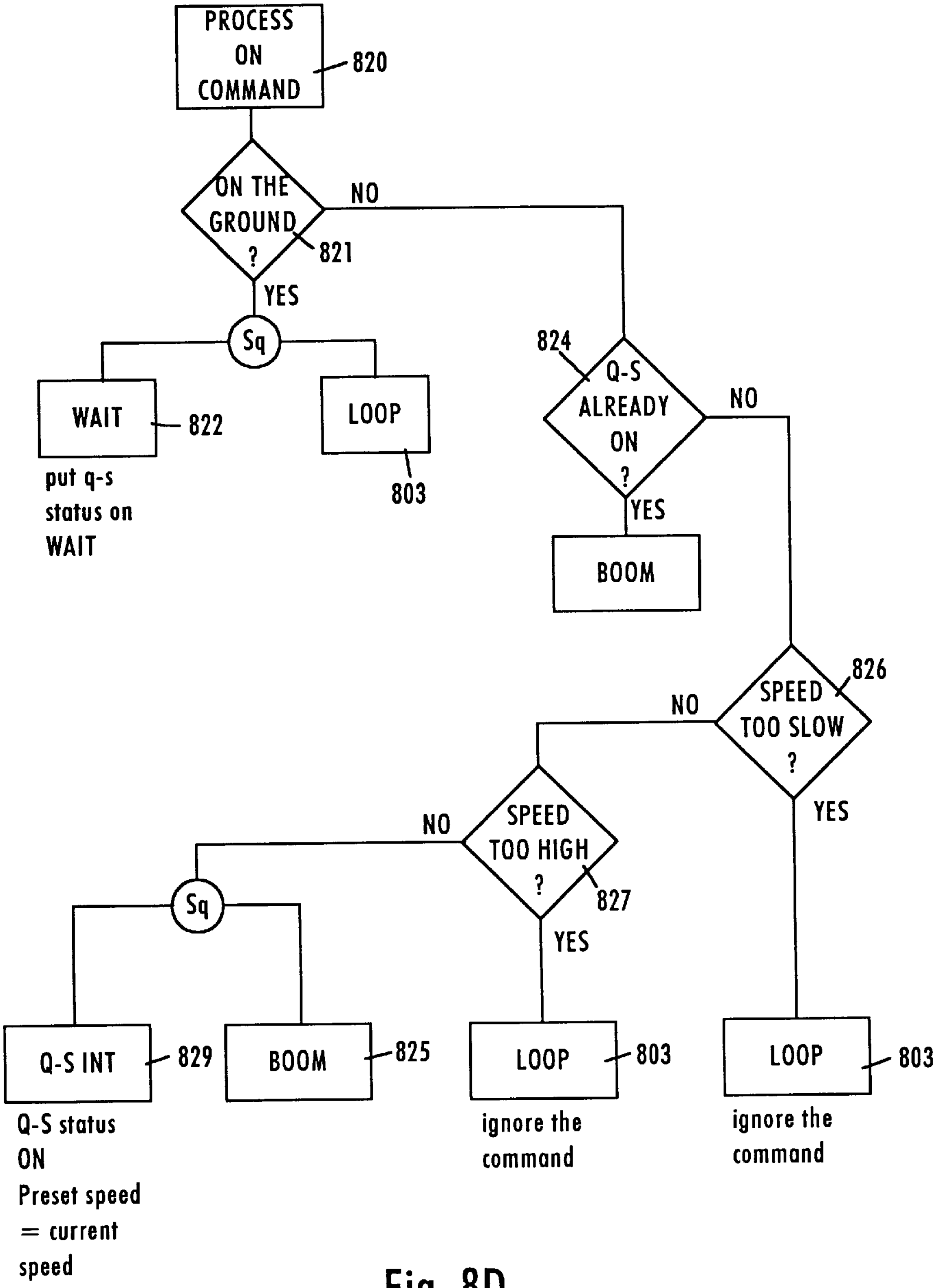

PROCESS ON COMMAND
820
ON THE GROUND ?
821
NO
YES
Sq
WAIT
822
put q-s status on WAIT
LOOP
803
824
Q-S ALREADY ON ?
NO
YES
BOOM
SPEED TOO SLOW ?
826
NO
YES
SPEED TOO HIGH ?
827
NO
YES
Sq
Q-S INT
829
Q-S status ON Preset speed = current speed
BOOM
825
LOOP
803
ignore the command
LOOP
803
ignore the command

Fig. 8D

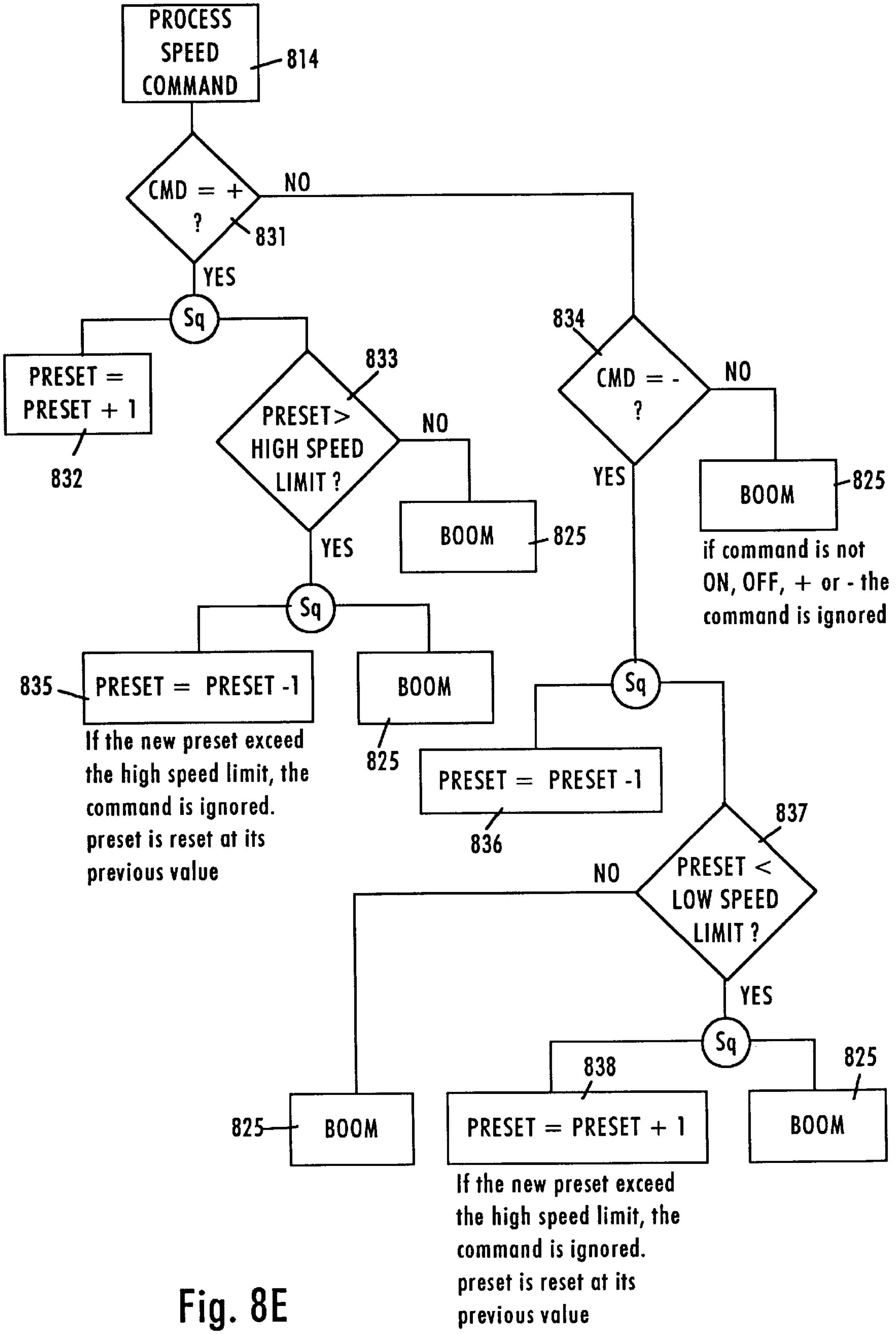

PROCESS SPEED COMMAND
814
CMD = + ?
831
NO
YES
Sq
PRESET = PRESET + 1
832
PRESET> HIGH SPEED LIMIT ?
833
NO
BOOM
825
YES
Sq
835
PRESET = PRESET -1
If the new preset exceed the high speed limit, the command is ignored. preset is reset at its previous value
BOOM
825
834
CMD = - ?
NO
BOOM
825
if command is not ON, OFF, + or - the command is ignored
YES
Sq
PRESET = PRESET -1
836
PRESET < LOW SPEED LIMIT ?
837
NO
YES
Sq
825
BOOM
838
PRESET = PRESET + 1
If the new preset exceed the high speed limit, the command is ignored. preset is reset at its previous value
825
BOOM

Fig. 8E

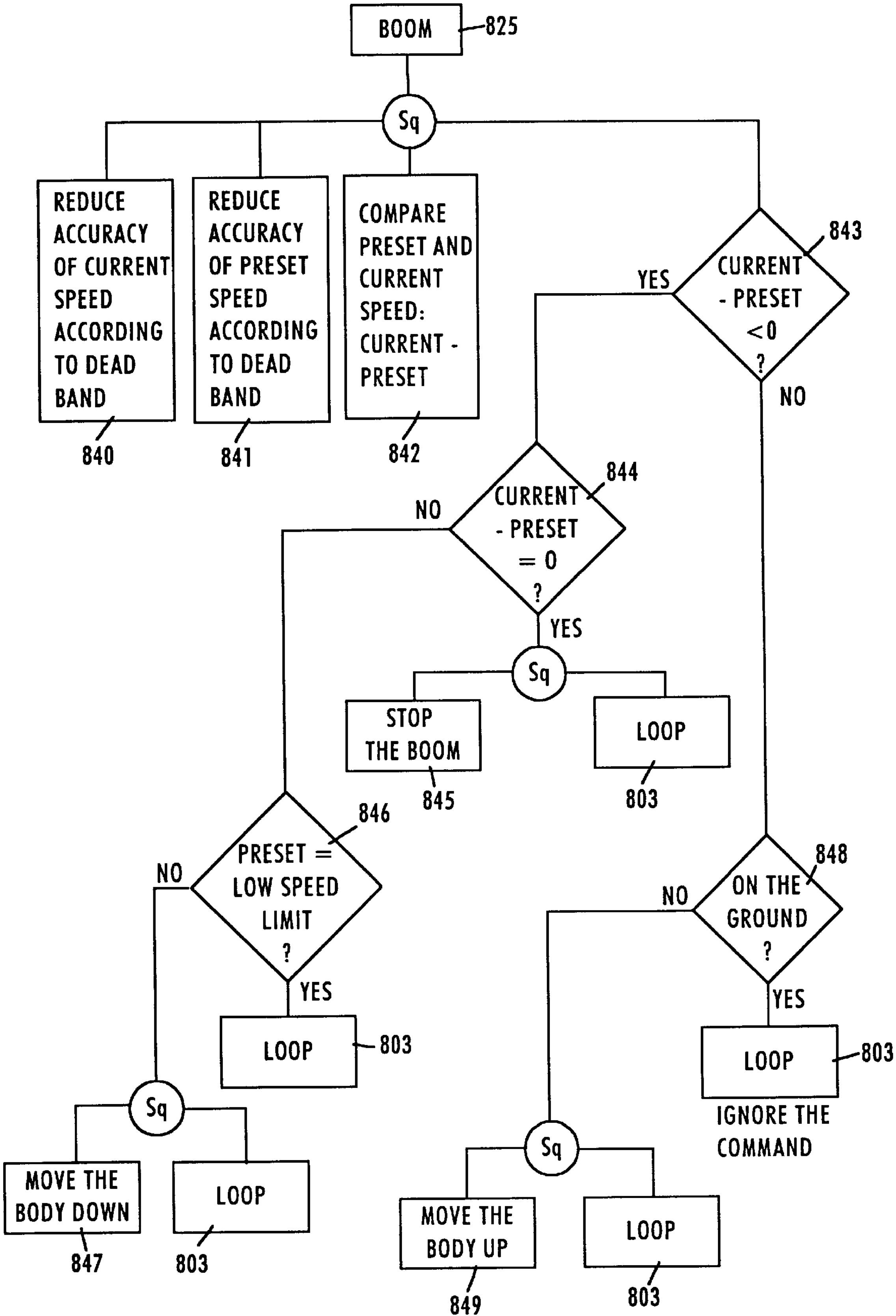

BOOM
825
Sq
REDUCE ACCURACY OF CURRENT SPEED ACCORDING TO DEAD BAND
840
REDUCE ACCURACY OF PRESET SPEED ACCORDING TO DEAD BAND
841
COMPARE PRESET AND CURRENT SPEED: CURRENT - PRESET
842
CURRENT - PRESET <0 ?
843
YES
NO
CURRENT - PRESET = 0 ?
844
NO
YES
Sq
STOP THE BOOM
845
LOOP
803
PRESET = LOW SPEED LIMIT ?
846
NO
YES
LOOP
803
Sq
MOVE THE BODY DOWN
847
LOOP
803
ON THE GROUND ?
848
NO
YES
LOOP
803
IGNORE THE COMMAND
Sq
MOVE THE BODY UP
849
LOOP
803

Fig. 8F

# ACTIVE FEEDBACK LOOP TO CONTROL BODY PITCH IN STOL/VTOL FREE WING AIRCRAFT

## CROSS REFERENCE TO RELATED APPLICATIONS

This application is a continuation-in-part of application Ser. No. 08/332,321, filed Oct. 31, 1994, now abandoned, which is a continuation of prior application Ser. No. 08/007,130 filed Jan. 22, 1993, entitled "STOL/VTOL FREE WING AIRCRAFT WITH ARTICULATED TAIL BOOM," now U.S. Pat. No. 5,395,073, the disclosure which is incorporated by reference herein in its entirety.

## TECHNICAL FIELD

The present invention relates to an active feedback control loop to maintain stability of a STOL/VTOL aircraft. The active feedback control loop of the present invention has particular application to a STOL/VTOL free wing aircraft with an articulated control boom or other control surfaces. However, it is intended that the use of the control loop disclosed herein on a fixed wing aircraft be considered within the scope of the present invention.

## BACKGROUND ART

As disclosed in U.S. Pat. No. 5,340,057, issued Aug. 23, 1994, and incorporated herein by reference, free wing aircraft, i.e., aircraft having a wing free for rotation about a spanwise axis to maintain a constant angle of attack with the relative wind, have been found to be particularly useful in short take-off and landing (STOL) and vertical take-off and landing (VTOL) applications. More specifically, the aircraft of the type described herein typically has a free wing comprised of left and right wings projecting on opposite sides of the fuselage and mounted to the fuselage for free joint pivotal movement about a spanwise axis forward of the aerodynamic centers and controlled pivotal movement relative to one another for roll control during vertical and horizontal flight, as well as transitions therebetween. Free wing aircraft are relatively immune to turbulence and the like and also may provide high lift and good anti-stall characteristics. Thus, free wing aircraft are particularly appropriate for remotely piloted vehicles (RPV) or unmanned aerial vehicles (UAV's) where low speed or near hovering flight is required. Additionally, the stability of the free wing makes it an ideal aerial platform for instrumentation mounts (video camera, infrared sensor or the like).

Although the free wing aircraft is highly stall resistant, during manned or unmanned low speed flight, it has been discovered that a velocity may be reached where, although a stall is not imminent, the aircraft may become unstable in yaw and pitch. Such conditions may occur in a UAV where the vehicle may be programmed to fly through a prescribed course using an internal navigation system (e.g., inertial navigation system GPS or the like) or in an RPV where the pilot may be controlling the aircraft remotely (e.g., radio control) and cannot receive the sensory feedback that a pilot receives in a manned aircraft.

Thus a control mechanism to control a free wing STOL/VTOL aircraft to maintain the aircraft in a stable region of the performance envelope would be highly desirable.

## SUMMARY OF THE INVENTION

It is therefore an object of the present invention to maintain a free wing aircraft within a stable realm of its performance envelope at zero or low indicated air speeds.

The control system of the present invention includes an air speed sensor for measuring air speed of the aircraft and outputting an air speed signal. A control processor, coupled to the air speed sensor, receives and processes the air speed signal from the air speed sensor and a speed control input signal and outputs a control surface control signal. A control actuator is coupled to the control processor and actuates an aircraft control surface in response to the control surface control signal.

The air speed sensor may include a shaft mounted impeller located in an airstream of the aircraft. The impeller rotates in response to air flow in the airstream. A rotational speed sensor, coupled to the impeller, measures a rotational speed of the impeller and outputs a rotational speed signal as the air speed signal. The rotational speed sensor may comprise an optical shaft encoder.

In an alternative embodiment, the air speed sensor may include a vane located in an airstream of the aircraft. The vane is deflected in response to air flow in the airstream. A position sensor coupled to the vane measures the position of the vane and outputs a position sensing signal as the air speed signal. The position sensor may comprises a first limit switch which is actuated when the vane is deflected by a first predetermined distance. The position sensor may further comprise a second limit switch actuated when the vane is deflected by a second predetermined amount.

The aircraft may comprise a free wing aircraft including a free wing rotatably coupled to a fuselage. In such an embodiment, the speed sensor may include an angular position sensor, coupled to the free wing and the fuselage, for measuring an angle between the free wing and the fuselage and outputting an angle measurement signal as the air speed signal.

The aircraft control surface may comprise a trim tab pivotally attached to a fuselage of the aircraft and coupled to the control actuator. The control actuator pivots the trim tab in response to the control surface control signal. In an alternative embodiment, the aircraft control surface comprises a control boom pivotally attached to a fuselage of the aircraft and coupled to the control actuator. The control actuator pivots the control boom in response to the control surface control signal.

A method of controlling an aircraft is provided. The air speed of the aircraft is measured and output as an air speed signal. The air speed signal is processed with a speed control input signal and a control surface control signal is output. An aircraft control surface is actuated in response to the control surface control signal.

## BRIEF DESCRIPTION OF DRAWINGS

FIG. **1** is a rear perspective view of an aircraft incorporating a first embodiment of the present invention;

FIG. **2** is a cross-section view of the fuselage of the aircraft of FIG. **1** depicting one embodiment of an altitude control system of the present invention;

FIG. **3** is a control block diagram, partly schematic, for the embodiment of FIG. **1**;

FIG. **4** is a cross-section view of the preferred embodiment of the present invention depicting a free wing aircraft with an articulated control boom and the air speed hold system of the present invention;

FIG. **4A** is a cross-section view similar to FIG. **4** of an alternative embodiment of the present invention.

FIG. **5** is a front view of the aircraft of FIG. **4**; and

FIG. **6** is a perspective view of an air speed hold system for use in the present invention;

FIG. **7** is a cross-section view of a second embodiment of an air speed hold system for use in the present invention;

FIGS. **8**, **8**A–**8**F are block diagrams of the feedback control program for use with the present invention.

## BEST MODE FOR CARRYING OUT THE INVENTION

Free wing aircraft have been developed by the present inventors, for example, as set for in co-pending application Ser. No. 08/007,130, and U.S. Pat. No. 5,340,057. A first embodiment of a free wing aircraft, as set forth in U.S. Pat. No. 5,340,057, utilizes control flaps on the fuselage to maintain fuselage angle and thrust angle to allow the airplane to operate in STOL/VTOL regions, and to maintain and control direction of flight. A second embodiment of a free wing aircraft, set forth in co-pending application Ser. No. 08/007,130, employs an articulated control boom to control fuselage angle and thrust angle, to allow the aircraft to operate in VTOL/STOL regions, and to maintain and control direction of flight.

FIG. **1** is an illustration of yet another embodiment of a free wing aircraft **100** which operates without a traditional aircraft tail. A fuselage **101** houses the aircraft engine, fuel supply, and the like, which is used to drive propeller **102**. While a single propeller for the propulsion system is illustrated at **102** in FIG. **1**, it will be appreciated that other types of propulsion systems may be utilized. For instance, the propulsion system may comprise counterrotating propellers or other thrust generating devices including jet engines, ducted fans, unducted fans, rocket motors or the like.

Attached to fuselage **101** is a free wing **104**. As disclosed in the above-reference patents, free wing **104** is free to rotate or pivot about its spanwise axis **122**. Free wing **104** includes left and right wings **104***a* and **104***b*, extending from opposite sides of fuselage **101** and which wings **104***a* and **104***b* are coupled together to collectively freely pivot about axis **122**. The left and right wings **104***a* and **104***b* can be, however, adjustable in pitch relative to one another, as described in the above-referenced patents. Free wing **104** may also be provided with ailerons or flaps **110***a* and **110***b* to maintain or control direction or provide additional lift.

Fuselage **101** is provided with one or more trim tabs **109** to control vehicle direction and attitude. As shown in FIG. **1**, trim tabs **109** may comprise a pair of tabs mounted on the upper surface of fuselage **101** on either side of the central axis of fuselage **101** and may be formed similar to a speed brake or the like. Alternately, trim tabs **109** may be formed in a similar manner to ailerons. Trim tabs **109** may be selectively or differentially operated to compensate for torque generated by propeller **102**, especially in hovering or near hovering operating conditions. To this end, trim tabs **109** may be provided asymmetrically.

Trim tabs **109** may be driven by various known aircraft linkages and actuators, including manual control wires, push-pull control tubes, hydraulic systems, screw jacks (electric or hydraulic) or the like. In the best mode contemplated, as shown in FIG. **2**, an actuator **106** is coupled to each of trim tabs **109** by means of a mechanical control linkage **107**. Preferably, actuator **106** comprises an electric servo-actuator, such as a model FP S-148, manufactured by Futaba corporation, or model SSPS105 manufactured by TONE.

Referring again to FIG. **2**, housed within fuselage **101** are control circuits which may include the feedback control of the present invention as well as flight controls. Flight controls may comprise radio controls for an RPV, an automated (e.g., computer) control for an UAV, or traditional pilot controls (e.g., joystick, control yoke, rudder pedals, or the like) for a manned aircraft. Alternately, any combination of these controls may be provided. For example, for an RPV, some automated controls may be provided to allow for partial automated control of vehicle functions. Similarly, in a manned vehicle, some automated controls (e.g., autopilot) may be provided. Also, as is known in the art, so-called "fly by wire" control systems may be provided to dynamically stabilize an aircraft in any of RPV, UAV or manned embodiments.

The control system of the present invention will be described generally with reference to FIG. **2**. Free wing **104** is coupled to fuselage **101** at axis **122** by a structural tube **130**. A position sensor **120** is provided, coupled to structural tube **130** by a linkage **121**. Position sensor **120** determines the angle between free wing **104** and the centerline of fuselage **101** and measures the changes in this angle. Position sensor **120** may comprise any one of various known sensors including but not limited to a potentiometer, optical sensors, Hall effect sensors or the like. In the preferred embodiment, position sensor **120** comprises a potentiometer.

Position sensor **120** and actuator **106** are both connected to a processor **103** which may comprise a microprocessor control, hydraulic, pneumatic or fluidic control, programmable logic array, electronic control or the like. It is preferred that processor also function as a receiver for receiving pilot commands, as discussed below. Processor **103** may additionally comprise a control circuit, as discussed above, for controlling the aircraft, a portion of which may be programmed to implement the feedback loop of the present invention. In the preferred embodiment, processor **103** comprises a processor receiver model number 7UAPS control system manufactured by Futaba corporation, or an equivalent model manufactured by ACE R/C.

FIG. **3** is a schematic representation of the operation of the processor logic for the embodiment of FIGS. **1** and **2**. In FIG. **3**, a pilot command is input to processor **103**. Specifically, the embodiment of FIGS. **2** and **3** describe an altitude hold system. The pilot command may comprise a manual input from a human pilot, a computer command from a fly by wire system, an automated (or programmed) command from an UAV control system or a remote control command (e.g., radio control) received in an RPV control system. Typically, the pilot command may comprise a speed command, commanding the aircraft to fly at a particular ground speed or air (indicated) speed. However, it is also contemplated within the scope of this invention that the pilot command may comprise an altitude command, as discussed below with reference to FIGS. **8**A–**8**E, or any other suitable command.

Processor **103** outputs a command signal to actuate servo-actuator **106** to control trim tabs **109**. The command signal may be, for instance, a voltage, a pulse width modulation, a digital word, or a frequency. As discussed above, the operation of trim tabs **109** may be used to control fuselage angle and thus thrust angle. By altering thrust angle, aircraft **100** may be slowed to hovering or near hovering conditions without substantially reducing lift. However, below certain velocities, free wing aircraft **100** may enter an unstable portion of the performance envelope where excessive yaw or roll may be induced, as the flow of air over the control surfaces of the airplane is reduced to the point where effective control is lost.

In order to prevent free wing aircraft from entering an unstable domain, the command signal from processor/

receiver **103** may be altered by a voltage generated by position sensor **120** to form a modified command signal, which is then fed to servo-actuator **106** to actuate trim tabs **109**. As position sensor **120** is coupled to pivot point **122**, the amount of modification to the command signal is directly proportional to the change in angle between the centerline of fuselage **101** and free wing **104**. Position sensor **120** may alternatively output a position angle which may be fed to processor **103**, in which case processor **103** modifies the command signal to servo-actuator **106**.

FIGS. **4** and **5** are views of the preferred embodiment of an air speed hold system of the present invention for a free wing aircraft having an articulated control boom. Such an aircraft is disclosed, for example, in co-pending application Ser. No. 08/007,130.

A center fuselage portion **601** houses the aircraft engine, fuel supply, and the like, which is used to drive propeller **602**. Although depicted here as driven by a propeller **602**, free wing aircraft **600** may also be driven by counterrotating propellers or other thrust generating devices mounted to the fuselage including jet engines, ducted fans, unducted fans, rocket motors or the like.

Housed within fuselage **601** are control circuits **626** which may include the feedback control of the present invention as well as flight controls. Flight controls may comprise radio controls for an RPV, an automated (e.g., computer) control for an UAV, or traditional pilot controls (e.g., joystick, control yoke, rudder pedals, or the like) for a manned aircraft. Alternately, any combination of these controls may be provided. For example, for an RPV, some automated controls may be provided to allow for partial automated control of vehicle functions. Similarly, in a manned vehicle, some automated controls (e.g., autopilot) may be provided. Also, as is known in the art, so-called “fly by wire” control systems may be provided to dynamically stabilize an aircraft in any of RPV, UAV or manned embodiments. In the preferred embodiment of FIG. **4**, control system **626** includes a radio control receiver.

Attached to fuselage **601** is a free wing **604** which comprises a pair of wings **604***a* and **604***b* (i.e., left and right) which are coupled together to a hinge tube and pivot mechanism so as to allow free wing **604** to pivot relative to fuselage **601** around pivot point **622**. Free wing **604** may also be provided with ailerons or flaps (not shown) to maintain or control direction or provide additional lift.

Attached to fuselage **601** is an articulated control boom **609** which is provided to control vehicle direction and attitude. Articulated boom **609** may include both rudder and elevator or other combination of control surfaces (e.g., “ruddervator”). In addition, although depicted as a single articulated control boom in FIG. **5**, twin articulated control booms may also be provided.

Articulated control boom **609** is articulated relative to fuselage **601**. Articulated control boom **609** may be driven by various known aircraft linkages and actuators, including manual control wires, push-pull control tubes, hydraulic systems, screw jacks (electric or hydraulic) or the like. In the preferred embodiment, the actuator **606** comprises a screw jack type actuator as depicted in FIG. **4** wherein the output of actuator **606** turns a screw jack **606***a* meshing with teeth **609***a* on articulated control beam **609**. In an alternative embodiment, depicted in FIG. **4**A, actuator **606** drives a motor **607** including an output gear **607***a*. Gear **607***a* drives a jack screw **607***b* connected to articulated tail boom **609** via a linkage **607***c* and a control rod **607***d*.

In flight, the aircraft **600** of FIG. **4** receives control signals though radio control **626** to control speed, direction, and

attitude of aircraft **600**. In order to control thrust angle of aircraft **600**, control signals from radio control **626** may drive control circuit **603** to actuate actuator **606** to change the relative angle between articulated control boom **609** and fuselage **601**. Articulated control boom **609** maintains a relatively constant angle relative to the angle of attack of aircraft **600**. By altering the angle between fuselage **601** and articulated control boom **609**, the thrust angle of aircraft **600** is altered, providing increased or decreased lift and thrust vectoring. By altering thrust angle, aircraft **600** can operate in VTOL/STOL or near hovering conditions, while still achieving high speed flight.

As discussed above in connection with FIGS. **1** and **2**, however, at certain low speeds encountered in near hovering conditions, aircraft **600** may become unstable. Although in such low speed conditions, free wing **604** may not be stalled per se, the directional control of the aircraft may become unstable due to the lack of airflow over control surfaces of aircraft **600**.

In order to prevent aircraft **600** from entering such an unstable regime of operation, the control system of the present invention is provided to monitor air speed (indicated speed) of aircraft **600** and alter the relative angle between articulated control boom **609** and fuselage **601** to maintain aircraft **600** in a stable control region.

In the embodiment of FIG. **4**, an aircraft low speed sensor is used to measure air speed (indicated speed) of aircraft **600**. Traditional techniques for measuring aircraft indicated speed (e.g., pitot tube or the like) may be unsuitable for measuring aircraft speed at very low velocities (e.g., 35 knots or less). The accuracy and linearity of a pitot tube drop off rapidly with the decrease between total and static pressure. Further, pressure sensors capable of measuring such low pressure differentials (typically in inches or tenths of an inch of water) are costly and cumbersome. Low cost or compact pressure sensors generally do not have the accuracy necessary to measure such low pressure differentials.

Thus, the control system of the present invention incorporates two air speed indicators for indicating low aircraft speeds. FIG. **6** depicts the preferred embodiment of the airspeed indicator **650** of the present invention, illustrated mounted on aircraft **600** in FIGS. **4** and **5**. Airspeed indicator **650** comprises a small impeller **652** mounted to rotating shaft **658** coaxially with speed disk **654**. Speed disk **654** is provided with an orifice or grating **659** and optical sensor **656**. Optical sensor **656** senses light from a light source (not shown) passing through speed disk **654**. Although only one hole **659** is depicted in FIG. **6**, other numbers of holes may also be used, along with an grating or chopper type wheel. In addition, although in the preferred embodiment an optical sensor is used, other types of rotational sensors may also be used, including inductive or magnetic sensors, Hall effect sensors or the like.

The output of sensor **656** is depicted as waveform **670**, a series of pulses synchronous with the rotation of speed disk **654**. Waveform **670** is fed to counter **671** which counts the number of pulses over a standard period of time and outputs an analog or digital signal proportional to the rotational speed of speed disk **654**. The relationship between aircraft indicated speed (airspeed) and rotational speed (e.g., RPM) of impeller **652** is fairly linear for low speed. However, since in the present invention only a given airspeed, in the linear range, need be detected, non-linearities in the RPM/airspeed relationship need not be compensated.

Referring back to FIG. **4**, the output of counter **671** is fed to control circuit **603**. Control circuit **603** include signal processor **603***a* and **603***b*, and differential amplifier **603***c*. Signal processor **603***a* receives a control signal from radio controller **626** and converts this signal into an actuator control signal **606**. Signal processor **603***a* may comprise an A/D converter, analog amplifier, digital processor or similar components, as is known in the control art. Further signal processor **603** may comprise a portion of a microcontroller, as will be discussed below in conjunction with FIGS. **8**A–8F.

Signal processor **603***b* similarly receives the output from counter **671** and processes this signal to generate a modifying signal to modify the actuator control signal output from signal controller **603***a*. Digital information representative of the actual value of the outputs of signal processors **603***a* and **603***b* are fed to differential amplifier **603***c* where the difference of the two signals is output. If the airspeed of aircraft **600** is below a predetermined threshold (e.g, 25 knots), signal processor **603***b* may generate a positive control voltage to increase the relative angle between articulated control boom **609** and fuselage **601**, (i.e., decrease thrust angle) and thus increase airspeed of aircraft **600**. If aircraft **600** is above the predetermined speed, signal processor **603***b* may generate a negative control voltage to decrease the relative angle between articulated control boom **609** and fuselage **601** and thus decrease the air speed down to the predetermined air speed. If aircraft **600** is at the predetermined speed, signal processor **603***b* may generate no signal. Actuator **606** may be provided such that for a given output voltage, a proportional relative angle is maintained between articulated control boom **609** and fuselage **601**.

FIG. **7** depicts an alternative embodiment of the airspeed indicator of the present invention. Sensor **450** of FIG. **7** comprises vane **452** placed in the airstream of aircraft **600**. At relatively high vehicle speeds, vane **452** is deflected rearward by air flow. Spring **451** is provided to pull vane **452** against the predominate air flow. When aircraft **600** falls below a predetermined air speed, pressure on vane **452** due to air flow decreases, and spring **451** pulls vane **452** forward.

Limit switches **459***a* and **459***b* are provided coupled to vane **452**. When no air flow is present, vane **452** is pulled forward by spring **451** against limit switch **459***a*, grounding a signal line to control **453**. When a first predetermined air flow is present, vane **452** is deflected rearward, as shown in the arrow in FIG. **7**, and cane **452** breaks contact with limit switch **459***a*. When a second, greater, predetermined air flow is present, vane **452** is deflected further rearward, activating limit switch **459***b* and grounding a signal wire to control **453**. Thus, two signals may be provided to control **453** to determine whether air flow is below a first predetermined limit, or above a second predetermined limit. Control **453** may process these signals and output a third signal indicating relative air speed.

The use of first and second limit switches **459***a* and **459***b* provides a built in dead-band between lower and upper air speed limits. This dead-band may compensate for transient wind conditions, gusts, or the like, or transient speed changes in the aircraft. Alternately, one limit switch may be provided to measure a speed threshold condition, without departing from the spirit and scope of the present invention.

Adjustment screws **457** are provided to adjust the threshold air speeds needed to activate limit switches **459***a* and **459***b*. Limit switches **459***a* and **459***b* may be suitably replaced by a linear potentiometer, Hall effect sensor or the like to provide a position signal to continuously measure the deflection of vane **452**. The dead-band provided by limit switches **459***a* and **459***b* may be provided by suitable programming control **453** to compare the output of a continuous position sensor.

FIG. **8** is a basic flow chart for the processor control of the present invention. FIGS. **8**A–8F is a detailed processor control flow chart for the embodiment of FIGS. **4** and **5**. Referring first to FIG. **8**, processing begins at step **802** with the initialization routine which sets the initial values of the processor. The airspeed of the aircraft is read in step **805**, whereupon the current airspeed is compared to the preset airspeed (step **843**). If the difference between the current airspeed and the present airspeed is not greater than or equal to 0, i.e., the current airspeed is less than the preset airspeed, processing passes to step **848**, where it is determined whether the aircraft is on the ground. If the aircraft is on the ground, processing passes back to step **805**, where the airspeed of the aircraft is again read. If the aircraft is not on the ground, then the control surface is actuated at step **849**, whereupon processing passes back to step **805**.

If it is determined in step **843** that the current airspeed is greater than or equal to the preset airspeed, processing passes to step **844**, wherein it is determined whether the current airspeed equals the preset airspeed. If the current airspeed does not equal the preset airspeed, i.e., the current airspeed is less than the preset airspeed, the control surfaces are actuated at step **847**, and processing returns to step **805**. If the current and preset airspeeds are equal, the control surface, if in motion, is stopped (step **845**), and processing returns to step **805**. Thus, it can be seen once actuation of the control surface is initiated, either at step **849** or step **847**, the control surface will continue to be actuated until the current airspeed equals the preset airspeed, whereupon the movement of the control surface will be stopped at step **845**.

Turning to FIGS. **8**A–8F, while the processor for the embodiment of FIGS. **4** and **5** is shown, it is expected that one skilled in the art could modify the processor control of FIGS. **8**A–8F to control the embodiment of FIGS. **1** and **2**. A suitable microprocessor may be used to implement the control system of the present invention. In the preferred embodiment, an eight bit microprocessor from the Intel™ MCS-51 family of microprocessors (e.g., 8051, 8031, 8032 or the like) may be used.

FIG. **8**A depicts the main control loop for the program. In the flow charts of FIGS. **8**A–8F, the nomenclature "Sq " indicates "sequence", indicating a sequence of iterative control loop routines. Upon initial startup, indicated at step **801**, the processor goes through an initialization routine **802** wherein a number of initial values are set, as depicted in step **804**. The parameters, used by the program, are defined and set according to preprogrammed or selected value. The minimum air speed is set at a value below which the aircraft may become instable due to the lack of airflow over control surfaces. The maximum air speed is set at a value above which the incidence of the boom angle will not be significant and the air speed sensor will not operate in a linear range. The dead band is set to limit over controlling of the aircraft due to minor variation such as turbulence or the like. The airspeed sensor (Q-S) status is set to off, allowing manual command of the boom angle. After initialization, processing passes to iterative control loop **803**.

FIG. **8**B depicts the sequence for control loop **803**. The processor first reads airspeed in step **805** and stores this value in a register. Any conversion necessary to convert airspeed sensor input to a an airspeed value are performed here (e.g., rpm to knots). Next, the processor reads an input command as indicated in step **806**. Step **806** includes the sequence of steps **807** and **808**. In step **807**, the processor reads an input command from an I/O device or input register. In step **808**, the read command is modified to a usable format and stopped at a specific address. The major commands of interest are "Faster" and "Slower" (increase or decrease airspeed) which is generally accomplished by a combination of engine speed changes and changes in boom angle for thrust vectoring. The OFF command disables the control loop thus enabling the manual control boom for special purposes. The ON command enables the control loop with all its associated logic described below. In step **808**, the commands are converted for processing. In order to accelerate the process of the ground command, the carry is used for the intermediate processing of this command, as discussed below. Processing passes to the process command step **809**.

FIG. **8**C depicts the process sequence for process command step **809**. In decision step **810**, register b**0** is polled to determine whether an OFF command has been received. The sequence of steps **811**, **812**, and **803** are followed for the OFF command. In step **811**, a loop counter is decremented. In step **812** the air speed sensor (Q-S) status is set to off and the boom control deactivated. In step **803**, processing passes back the LOOP sequence described above in connection with FIG. **8**B.

If an OFF command has not been received, processing passes to decision step **814** to determine whether an ON command has been received in register b**1**. If an ON command is present, the loop counter is decremented in step **819** and the ON command is processed in step **820**. The ON command is used to reactivate the feedback control of the present invention after an OFF command had be sent, or to reinitialize the feedback control.

FIG. **8**D depicts the sequences in the process ON command step **820**. In decision step **821**, the control determines whether the aircraft is on the ground. Since the aircraft could be damaged by attempting to move the boom on the ground (or ground personnel could be injured) it may be necessary to disable to boom control when the aircraft is on the ground. A weight on wheel switch or a proximity sensor such a radar, sonar, lidar, or the like may be input to the controller to determine whether the aircraft is in close proximity to the ground. If the aircraft is determined to be on the ground, processing passes to step **822** where a wait status is set. After the aircraft is cleared from the ground, this wait status will be cleared and the ON command will be processed as usual. After step **822**, the processing passes back to the loop sequence **803**.

If the aircraft is not on the ground, processing passes to step **824** to determine whether the feedback control has already been activated. If the feedback control is already been activated, processing passes to boom step **825** described below in connection with FIG. **8**F. If the feed back control has not already been activated, processing passes to steps **826** and **827**. Steps **826** and **827** determine whether the aircraft is operating within a speed range defined for the feedback control of the present invention. Since the feedback control is provided primarily for low speeds, the control system may not operate properly during high speed flight. Similarly, if the airspeed is below a preset limit of the feedback control, the system will also fail to operate properly as the aircraft might be in the range of instability due to the lack of airflow over the control surfaces. In this event, the ON command is ignored, and processing passes back to loop **803**.

If the aircraft airspeed is within predetermined limits, processing passes the sequence formed by steps **829** and **825**. In step **829**, the airspeed sensor is initialized, the boom control is set to the ON state, and the preset speed (desired control speed) is set to the current speed. Processing then passes to boom step **825** described below in connection with FIG. **8**F.

Referring to FIG. **8**C, if an ON or OFF command has not been received, i.e., a FASTER, SLOWER or no command has been received, processing passes to the sequence formed by steps **815** and **816**. In step **815**, the loop counter is decremented. In step **802**, the loop counter is set to an initial value of 5. Thus, the speed command are processed only once every five loops. As a loop is set at the initial time constant of the system, i.e., 0.1 s, a speed command must be activated longer than 0.5 to be processed. In this manner, fast speed changes are avoided. Even if the speed command is to be ignored, i.e., the loop counter has not reached zero, the processing still passes to boom control step **825**.

FIG. **8**E depicts the sequence for processing an input speed command. From step **817**, processing passes to decision step **831**. If the input speed command calls for increased speed (i.e., register b**2** is high), processing passes to the sequence depicted in steps **832** and **833**. In step **832**, the preset speed in incremented. Here the preset speed is depicted as being incremented by one, however, other rates of incrementation may be used (e.g., five) to increase the response of the system. In addition the present speed may be in MPH, KPH, knots, or arbitrary units. In this embodiment, the preset speed is the target speed which the aircraft control system attempts to maintain. In decision step **833**, it is determined whether the preset speed exceeds an internally set high speed limit. The high speed limit is provided such that the control system will not attempt to control the speed of the aircraft beyond the range suitable for the control system (e.g., beyond the range of the air speed sensor, or high speed flight). If the present speed is below the internally set high speed limit, processing passes to boom control step **825**. If the present speed is above the internally set high speed limit, processing passes to steps **835** and **825**. In step **835**, the preset limit is decremented to its previous value, and processing passes to boom control step **825**.

If a decrease speed command is present, as indicated in decision step **834** in FIG. **8**E, processing passes to the sequence represented by steps **836** and **837**. Otherwise, processing passes to boom control step **825**. In step **836**, the preset speed is decreased by one or another nominal value as discussed above. The new preset speed is compared to a internally set low speed limit in step **837**. This low speed limit is the critical speed discussed above, where the aircraft may enter an unstable region of the performance envelope. If the preset speed is above the internally set low speed limit, processing passes to boom control step **825**. If the preset speed is below the internally set low speed limit, the present speed in incremented to its previous value in step **838** and processing passed to boom control step **825**.

FIG. **8**F depicts the sequence of steps for boom control step **825**. From step **825**, processing passes through a series of steps **840** through **843**. In steps **840** and **841** the accuracy of the current (actual) aircraft speed and preset speed are reduced in accordance with the selected deadband. Therefore, the deadband can be ignored in the following processing as it already has been considered. In step **842** the preset speed and correct (actual) aircraft speed are compared. Ideally, the current speed should equal the preset speed, within a predetermined deadband. If the current speed is less than the preset speed (i.e., aircraft is going too slow), as decided in decision step **843**, processing passes to decision step **848**. In step **848** the processor determines whether the aircraft is on the ground, using weight on wheel switch, proximity sensors or the like as discussed above.

If the aircraft is on the ground, the boom control command is ignored and processing returns to loop step **803**. As discussed above, moving the boom (or fuselage) on the ground can result in aircraft damage (e.g., propeller strike) or injury to ground crew. If the aircraft is not on the ground, processing passes to the sequence formed by steps **849** and **803**.

In step **849**, the body (fuselage) of the aircraft is moved "up" relative to the angle of attack (i.e., the boom is raised relative to the fuselage). In flight, since the free wing and articulated control boom will maintain a relatively constant angle with regard to the angle of attack of the airplane, the fuselage will change angle as a result of changes in boom angle. Changing the angle of the fuselage allows for the use of vectored thrust, decreasing the speed of the aircraft and allowing for near hovering motion. Lowering the boom will allow the aircraft to increase speed.

If the current and preset speed are nearly identical (within the deadband discussed above), as determined in step **844**, processing passes to the sequence formed by steps **845** and **803**. The boom is stopped (if in motion) and processing passes back to loop **803**. Otherwise it is presumed that the current speed is above the present speed (i.e., aircraft is going too fast) and processing passes to step **846**. If the preset speed is at the internally set lower limit, as determined in decision step **846**, processing in interrupted and returns to loop **803**. If the preset speed is not at the lower limit, processing passes to the sequence formed by steps **847** and **803**. The body (fuselage) is lowered (i.e., boom is raised) such that the amount of vectored thrust is increased and the aircraft is slowed. Processing then passes to loop **803** and the process continues.

It should be noted that various aspects of the three embodiments of the present invention illustrated herein may be suitable interchanged or used in combination. For example, the flow sensors of FIGS. **6** and **7** may be suitably adapted for use with the embodiment of FIGS. **1** and **2**. Similarly, the embodiment of FIGS. **4** and **5** may utilize free wing angle in order to control the angle of the articulated control boom. It will be appreciated by one of ordinary skill in the art that the underlying concept between all three embodiments is the use of a fixed position, angle or speed sensor (three interrelated values) to control a control surface (aileron, trim tab, articulated control boom) to maintain stability of a free wing aircraft.

It will be readily seen by one of ordinary skill in the art that the present invention fulfills all of the objects set forth above. After reading the foregoing specification, one of ordinary skill will be able to effect various changes, substitutions of equivalents and various other aspects of the invention as broadly disclosed herein. It is therefore intended that the protection granted hereon be limited only by the definition contained in the appended claims and equivalents thereof.

We claim:

**1**. In a free wing aircraft including a free wing pivotably coupled to a fuselage, the improvement comprising an aircraft control system comprising:

air speed sensor mounted to the aircraft to measure air speed of the aircraft and output an air speed signal, and

a control processor, coupled to the air speed sensor, for receiving and processing the air speed signal from the air speed sensor and a speed control input signal, and outputting a control surface control signal; and

a control actuator, coupled to the control processor, for actuating an aircraft control surface in response to the control surface control signal;

wherein the speed sensor comprises:

an angular position sensor, coupled to the free wing and the fuselage, for measuring an angle between the free wing and the fuselage and outputting an angle measurement signal as the air speed signal.

**2**. A free wing aircraft comprising:

a fuselage,

a free wing being rotatably coupled to the fuselage,

air speed sensing means for measuring air speed of the free wing aircraft and outputting an air speed signal,

a control processor, coupled to the air speed sensing means, for receiving and processing the air speed signal from the air speed sensing means and a speed control input signal, and outputting a control surface control signal, and

a control actuator, coupled to the control processor, for actuating a control surface in response to the control surface control signal;

wherein the speed sensing means comprises:

angular position sensing means, coupled to the free wing and the fuselage, for measuring an angle between the free wing and the fuselage and outputting an

angle measurement signal as the air speed signal.

**3**. A method of controlling an aircraft comprising the steps of:

measuring air speed of the aircraft and outputting an air speed signal,

processing the air speed signal with a speed control input signal and outputting a control surface control signal, and

actuating an aircraft control surface in response to the control surface control signal;

wherein the aircraft comprises a free wing aircraft including a free wing and a fuselage, the free wing being rotatably coupled to the fuselage, and the step of measuring further comprises the steps of:

measuring an angle between the free wing and the fuselage and outputting an angle measurement signal as the air speed signal.

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