

UNITED STATES PATENT AND TRADEMARK OFFICE

BEFORE THE PATENT TRIAL AND APPEAL BOARD

DJI EUROPE B.V.

Petitioner

v.

TEXTRON INNOVATIONS INC.

Patent Owner.

IPR2023-001105

U.S. Patent No. 8,332,082

**DECLARATION OF DR. WILLIAM SINGHOSE IN SUPPORT OF
PETITION FOR *INTER PARTES* REVIEW OF U.S. PATENT NO. 8,332,082**

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I, Dr. Singhose, declare as follow:

1. I have been engaged by Perkins Coie LLP on behalf of DJI Europe B.V. (“Petitioner”), to provide this Declaration concerning technical subject matter relevant to the petition for Inter Partes Review (“Petition”) of U.S. Patent 8,332,082 to Christensen (“the ’082 patent”).

2. I am over 18 years of age. I have personal knowledge of the facts stated in this Declaration and could testify competently to them if asked to do so. I have reviewed and am familiar with the specification and the claims of the ’082 patent. In general, I will cite to the specification of a United States patent using the following formats: (Patent No., Col:Line Number(s)) or (Patent No., Paragraph Number(s)). For example, the citation (’082 patent, 1:1-10) points to the ’082 patent specification at column 1, lines 1-10. Also, for convenience, I use italics to denote limitations from the challenged claims.

3. All of the opinions contained in this Declaration are based on the documents I reviewed and my knowledge and professional judgment. In forming the opinions expressed in this Declaration, I reviewed the documents listed in the attached Appendix. I have also reviewed and am familiar with any other document referred to in this Declaration.

4. I have been asked to provide my technical opinions regarding how a person of ordinary skill in the art would have understood the claims of the '082 patent at the time of the alleged invention, which I have been asked to assume is the 2011 timeframe. For purposes of whether the teachings of the prior art render the claims of the '082 patent obvious, I have been asked to assume the date of March 30, 2011. I have also been asked to provide my technical opinions on how concepts in the '082 patent specification relate to claim limitations of the '082 patent. In reaching the opinions provided herein, I have considered the '082 patent, its prosecution history, and the references cited in the Appendix. I have also drawn on my own education, training, research, knowledge, and personal and professional experience.

I. Qualifications

5. I believe I am well qualified to render useful opinions on this matter. I will briefly summarize my knowledge, training, and experience here. A more detailed summary of my background, education, experience, and publications is set forth in my curriculum vitae (CV), which is submitted as DJI-1004.

6. I am being compensated for my time at my standard consulting rate. I am also being reimbursed for expenses that I incur during the course of this work. My compensation is not contingent upon the results of my study and analysis, the

substance of my opinions, or the outcome of any proceeding involving the '082 patent. I have no financial interest in the outcome of this matter or in any litigation involving the '082 patent.

7. Based on my education, research, and work experience, I am knowledgeable about the subject matter of the '082 patent and the related prior art. Specifically, my qualifications as an expert in the control of rotary aircraft, and other similar machines, stem from my prior work experience, as well as my experience as a Professor in the Woodruff School of Mechanical Engineering at Georgia Tech performing research, teaching, working, and consulting. I have hundreds of publications that are directed toward understanding and improving the control of rotorcraft and other machinery.

8. Regarding my education, I received a B.S. in Mechanical Engineering from the Massachusetts Institute of Technology ("MIT") in 1990. I then received an M.S. in Mechanical Engineering from Stanford University in 1992. Finally, I received a Ph.D. in Mechanical Engineering from MIT in 1997. After receiving my Ph.D., I was a postdoctoral researcher at MIT before becoming a professor at Georgia Tech in 1998.

9. At Georgia Tech, I have taught a graduate-level course on advanced control system design and implementation since 2001. I have co-authored a

textbook entitled “Command Generation for Dynamic Systems”, which focuses on designing control commands to move machines. The textbook presents numerous examples of various machines to which the theoretical concepts are applicable, including cranes, robots, and satellites. I have also developed a series of remote-operated experimental cranes and aerial lifts used extensively in educational activities.

10. My research focuses on the dynamics and control of machines. I have researched, developed experimental platforms, and published several papers relevant to aircraft and flight control. For example, I conducted research directed at controlling rotorcraft sling load operations which was sponsored by the National Rotorcraft Technology Center. This project involved researching the effects of suspended loads on the control of rotorcraft and techniques to reduce the swinging of the load and improve the response of such systems. The results of my research were presented in several papers. One such paper, “Dynamic Modeling and Simulation of a Remote-Controlled Helicopter with a Suspended Load”, studied the dynamic effects of loads suspended below the helicopter by cables and created a dynamic model of the loaded system. The paper documented the difficulty of maintaining a steady hover position after a horizontal movement of the helicopter while carrying a suspended load.

11. My paper “Input-Shaping and Model-Following Control of a Helicopter Carrying a Suspended Load” studied the effects of a heavy load suspended from a helicopter. The paper analyzed how the swinging of a suspended load can create challenges for model-following control architectures used in modern helicopter flight control systems due to the degradation of the tracking of the prescribed model dynamics, thereby degrading the control effectiveness. The paper described the use of input shaping with model-following control to reduce helicopter payload swing and improve the tracking of the prescribed model. The paper illustrates the design of an attitude-command flight control system that combines input-shaping and model-following control using dynamic models of a Sikorsky S-61 helicopter. It also shows the simulation results of the system for longitudinal and lateral repositioning movements.

12. My paper “Reducing Swing of Model Helicopter Sling Load Using Input Shaping” studied techniques for suppressing the swinging of a load suspended beneath a helicopter to improve safety and productivity. Specifically, the paper discusses the formation of a dynamic model to characterize the translational response of a model helicopter and sling load to lateral control inputs in order to investigate the use of input shaping on helicopters.

13. While I have addressed a few of the relevant papers above, other papers that I have published on rotorcraft include the following:

- J. J. Potter and W. Singhose, A Planar Experimental Remote-Controlled Helicopter with a Suspended Load, *IEEE/ASME Transactions on Mechatronics*, vol. 20, no. 5, pp. 2496-2503, 2015, doi: 10.1109/TMECH.2014.2386801.
- J. J. Potter, C. J. Adams, and W. Singhose, An Experimental Remote Controlled Helicopter with Suspended Load, in *2013 Int. Symp. on Mechatronics and its Applications*, Amman, Jordan, 2013.
- N. Johnson and W. Singhose, Dynamics and Modeling of a Quadrotor with a Suspended Payload, in *AIAA Aviation Forum Applied Aerodynamics Conference*, Atlanta, GA, 2018
- C. Adams, J. Potter, and W. Singhose, Modeling and Input Shaping Control of a Micro Coaxial Radio-Controlled Helicopter Carrying a Suspended Load, in *Int. Conference on Control, Automation and Systems*, Jeju, Korea, 2012.
- S. Ichikawa, A. Castro, N. Johnson, H. Kojima, and W. Singhose, Dynamics and Command Shaping Control of Quadcopters Carrying Suspended Loads, in *14th IFAC Workshop on Time Delay Systems TDS (IFAC-PapersOnLine)*, Budapest, Hungary, 2018, vol. 51, no. 14, pp. 84 - 88.

14. In addition to conducting research on rotorcraft dynamics and control, I have also performed research on air traffic control that was sponsored by NASA. That research program produced several publications directed to optimizing flight paths and reducing the taskload of air traffic controllers, such as:

- Vela, A., J. P. Clarke, E. Feron and W. Singhose (2011). The Relative Value of Trajectory Prediction and Conflict-Resolution Algorithms. IEEE/AIAA 30th Digital Avionics Systems Conference, Seattle, WA, 2011.
- Vela, A., K. Feigh, S. Solak, W. Singhose and J.-P. Clarke (2012). Formulation of Reduced-Taskload Optimization Models for Conflict Resolution. IEEE Trans. on Systems, Man, and Cybernetics 42(6): 1552- 1561.
- Vela, A., S. Solak, E. Feron, K. Feigh, W. Singhose and J.-P. Clarke (2009). A Fuel Optimal and Reduced Controller Workload Optimization Model for Conflict Resolution. Digital Avionics Systems Conference, Orlando, Florida.
- Vela, A., S. Solak, W. Singhose and J.-P. Clarke (2009). A Mixed Integer Program for Flight-Level Assignment and Speed Control for Conflict Resolution. IEEE Conference on Decision and Control, Shanghai, China.
- Vela, A. E., E. Feron, W. Singhose and J.-P. Clarke (2010). Control of Holding Patterns for Increased Throughput and Recovery of Operations. Digital Avionics Systems Conference, Salt Lake City, UT.
- Vela, A. E., E. Salaun, E. Feron, W. Singhose and J.-P. Clarke (2011). Bounds on Controller Taskload Rates at an Intersection for Dense Traffic. 2011 American Control Conference, San Francisco, CA.
- Vela, A. E., S. Solak, J.-P. Clarke, W. Singhose, E. Barnes and E. Johnson (2010). Near Real-Time Fuel-Optimal En Route Conflict Resolution. IEEE Trans. on Intelligent Transportation Systems 11(4): 826-837.

15. Finally, I am a named inventor on six (6) US patents directed at improving control systems:

- Singhose, W., Singer, N., Rappole, W., Derezinski, S., and Pasch, K., “Methods and Apparatus for Minimizing Unwanted Dynamics in a Physical System,” U.S. Patent 5,638,267, granted June 10, 1997.
- R. Eloundou, W. Singhose, “Command Generation Combining Input Shaping and Smooth Baseline Commands,” U.S. Patent 6,920,378, granted July 19, 2005.
- K. L. Sorensen, W. Singhose, and S. Dickerson, “Combined feedback and command shaping controller for multistate control with application to improving positioning and reducing cable sway in cranes,” U.S. Patent 7,970,521, granted June 28, 2011.
- W. Singhose and D. Kim, “Methods and Systems for Double-Pendulum Crane Control,” U.S. Patent 8,235,229, granted August 7, 2012.
- W. Singhose and Joshua Vaughan, “Methods and Systems for Improving Positioning Accuracy,” U.S. Patent 8,975,853, granted March 10, 2015.
- W. Singhose and Chen Chih Peng, “Crane Control Systems and Method,” U.S. Patent 9,132,997, granted September 15, 2015. • Khalid Sorensen and W. Singhose, “Crane Motion Control”, U.S. Patent 9,776,838, granted Oct. 3, 2017.

16. The combination of my education, research, and work experience in the area of rotorcraft control enables me to provide clarifying analysis and confident opinions on the subject matter of this IPR.

II. Understanding of Relevant Legal Principles

17. I am not a lawyer, and I will not provide any legal opinions. Although I am not a lawyer, I have been advised certain legal standards are to be applied by

technical experts in forming opinions regarding the meaning and validity of patent claims.

18. I understand that a patent claim is invalid if it is anticipated or obvious in view of the prior art, and that a claim can be unpatentable even if all of the requirements of the claim cannot be found in a single prior-art reference. I further understand that invalidity of a claim requires that the claim be anticipated or obvious from the perspective of a person of ordinary skill in the art at the time the invention was made.

19. I have been informed that a patent claim is invalid if it would have been obvious to a person of ordinary skill in the art. In analyzing the obviousness of a claim, I understand the following factors may be taken into account: (1) the scope and content of the prior art; (2) the differences between the prior art and the claims; (3) the level of ordinary skill in the art; and (4) any so called “secondary considerations” of non-obviousness, if they are present. I am not aware of any evidence of secondary considerations of non-obviousness relevant to the ’082 patent. I reserve the right to supplement this Declaration if Patent Owner (“PO”) introduces evidence of secondary considerations of non-obviousness.

20. I understand that to prove that prior art or a combination of prior art renders a patent obvious, it is necessary to:

- (1) identify the particular references that, singly or in combination, make the patent obvious;
- (2) specifically identify which elements of the patent claim appear in each of the asserted references; and
- (3) explain why a person of ordinary skill in the art would have combined the references, and how they would have done so, to create the inventions claimed in the patent. I further understand that exemplary rationales that may support a conclusion of obviousness include:
 - combining prior art elements according to known methods to yield predictable results;
 - simple substitution of one known element for another to obtain predictable results;
 - use of known technique(s) to improve similar devices (methods or products) in the same way;
 - applying a known technique to a known device (method or product) ready for improvement to yield predictable results;
 - “obvious to try” – choosing from a finite number of identified, predictable solutions with a reasonable expectation of success;
 - known work in one field of endeavor may prompt variations of the work for use in either the same field or a different field based on design incentives or other market forces if the variations are predictable to a person of ordinary skill in the art; and

- some teaching, suggestion, or motivation in the prior art that would have led a person of ordinary skill in the art to modify the prior art reference or to combine prior art reference teachings to arrive at the claimed invention.

21. I have been informed that, in considering obviousness, hindsight reasoning derived from the patent-at-issue may not be used.

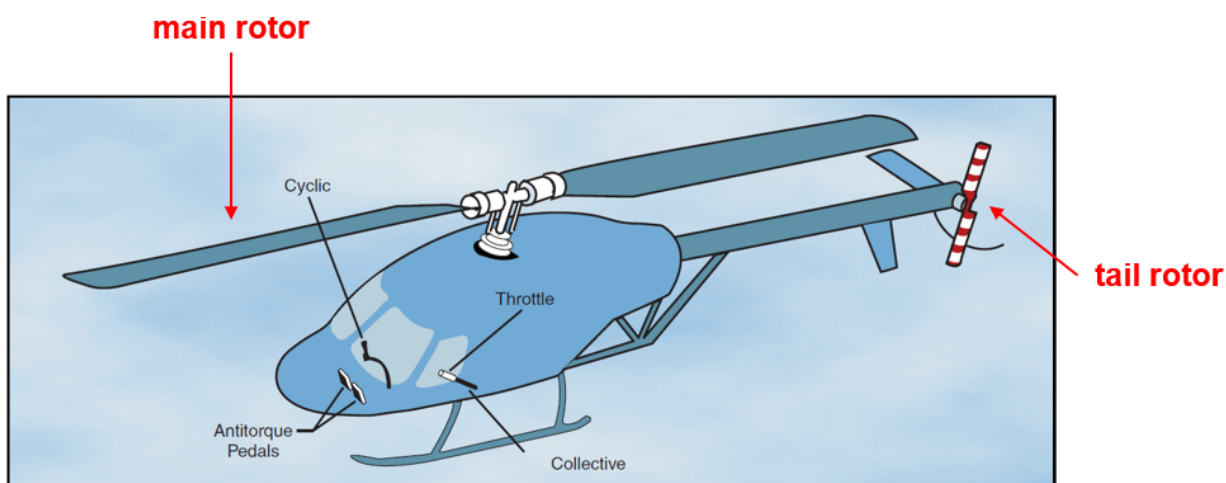
III. '082 Patent

22. The '082 patent “relates generally to flight control systems, and more particularly, to a flight control system having flight control laws which enable precise aircraft maneuvering relative to the ground.” (DJI-1001, 1:6-9.) The '082 patent focuses its discussion on “[a]ircraft that can hover and fly at low speeds” including “rotorcraft, such as helicopters and tilt rotors, and jump jets.” (DJI-1001, 1:14-16.) As I discuss below in the Technical Background section, use of a flight control system having the claimed flight control laws enabling the claimed precise maneuvering relative to the ground was extremely well-known and in use by the earliest possible priority date of the '082 patent (March 30, 2011).

A. Technical Background

23. Because the '082 patent is directed to rotorcraft, I focus my discussion in this section on rotorcraft. The main characteristic of a rotorcraft (e.g., helicopter) is the use of rotary wings to produce the thrust necessary for motion. A helicopter

typically uses two engine driven rotors—a main rotor and a tail rotor. These two rotors are shown in the figure below. The main rotor produces thrust, primarily for vertical lift, but also for directional control. The tail rotor is used to control the heading¹ of the helicopter. Changes in the angle of the main rotor produce propulsive forces for longitudinal and lateral motion.

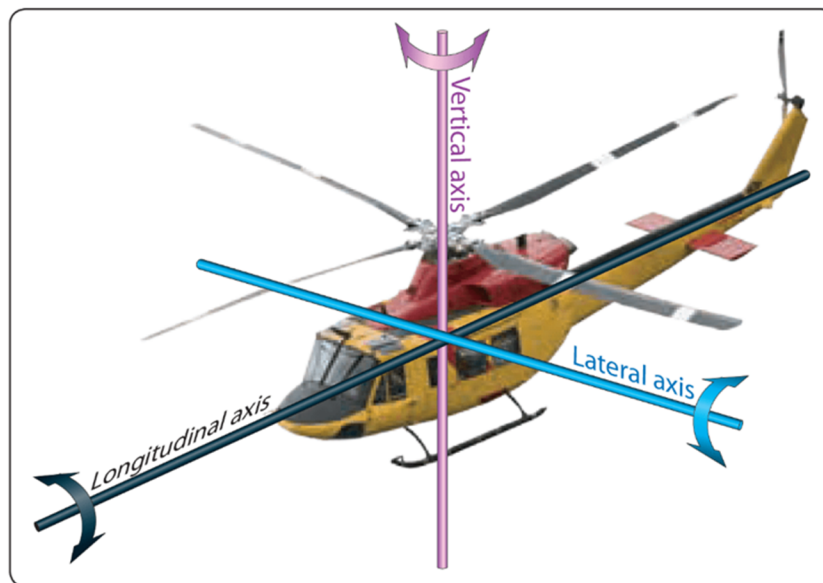


Rotorcraft Flying Handbook, Figure 1-7

24. A useful reference system for an aircraft (e.g., a helicopter) consists of three mutually perpendicular lines (axes) that intersect at the center of gravity of the aircraft. As shown in the figure below, the longitudinal axis passes through the nose and the tail of the aircraft. Rotation about the longitudinal axis is referred to

¹ The **heading** of an aircraft is the direction in which the nose of the aircraft points during flight. (DJI-1016, 1-6.)

as **roll** and is used for **lateral control**. The lateral axis extends from left to right. Rotation about the lateral axis is referred to as **pitch** and is used for **longitudinal control**. The vertical axis passes vertically through the center of gravity. Rotation about the vertical axis is referred to as **yaw** and is used to control the direction that the nose of the aircraft is pointing.



Helicopter Aerodynamics - Aircraft Theory of Flight (DJI-1024)

25. Attitude is the set of three angles that define the orientation of an aircraft (the rotation relative to the Earth-fixed coordinate system), and consist of pitch, roll, and yaw as described above. Therefore, attitude is a function of the helicopter's rotation about its axes. Attitude rates are the angular speeds of the aircraft, or the rates at which the orientation of the aircraft changes. These consist of pitch rate, roll rate, and yaw rate (sometimes called heading rate).

1. Pilot Controls

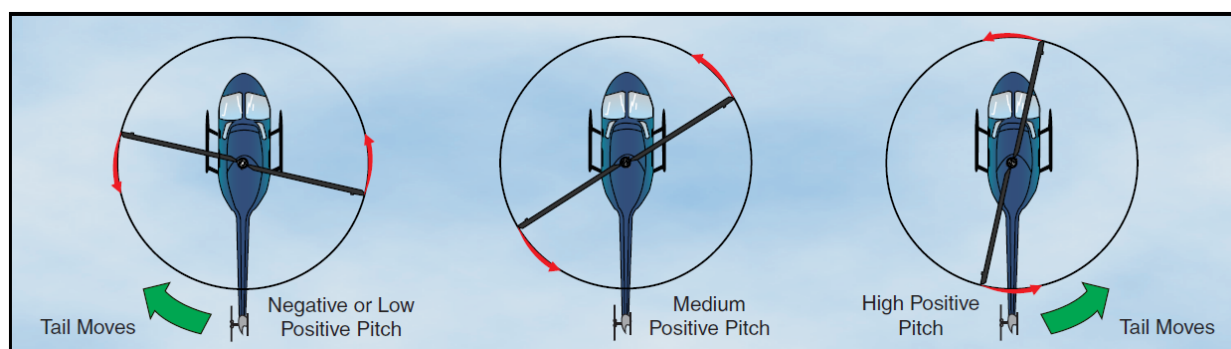
26. Helicopter cockpits often come equipped with the following controllers used by a pilot to control movement of the aircraft: a cyclic stick, a collective stick, and foot pedals. Each of these input devices allows a pilot to move the helicopter in a different way. (*See, e.g.*, DJI-1015, 4-1.) A cyclic stick can move forwards and backwards, as well as left and right. A cyclic stick is typically used for changing the helicopter's pitch and roll attitude angles by controlling the main rotor disk angle. Cyclic pitch control tilts the main rotor disc by changing pitch angle of the rotor blades in their cycle of rotation. (DJI-1015, 4-2.) When the main rotor disc is tilted, the horizontal force component moves the helicopter in the direction of the tilt. (DJI-1015, 4-2.) For example, if the cyclic stick is moved forward, the rotor disc tilts forward, resulting in forward acceleration. (DJI-1015, 4-3.) If it is moved aft, the disc tilts aft, resulting in backward acceleration. (DJI-1015, 4-3.) Change in the pitch angle is very strongly correlated with longitudinal motion; therefore, pitch control is generally synonymous with longitudinal control. To summarize very simply, the forward-backward movement of the cyclic stick controls longitudinal motion.

27. Rotation about the longitudinal axis (rolling the helicopter left or right) alters the helicopter's roll attitude, resulting in a sideward motion. Roll

control is generally synonymous with lateral control. Therefore, the left-right motions of the cyclic stick controls lateral motion.

28. The pedals control the pitch of the tail rotor blades. (DJI-1015, 4-3.) In addition to counteracting torque of the main rotor, the tail rotor controls the heading of the helicopter. (DJI-1015, 4-3.) That is, the pedals cause the helicopter to rotate about the vertical axis (when it is in level flight) to change its yaw angle.

29. As shown in the figure below, thrust of the tail rotor depends on pitch angle of the tail rotor blades. (DJI-1015, 4-3.) The pitch angle can be positive, negative, or zero. (DJI-1015, 4-3.) A high positive pitch angle tends to move the tail to the right; a low positive or negative pitch angle moves the tail to the left; and a medium pitch keeps the tail in line and maintains the yaw angle. (DJI-1015, 4-3.)



Rotorcraft Flying Handbook, Figure 4-6

30. Collective pitch control changes the pitch angle of all main rotor blades simultaneously (collectively). (DJI-1015, 4-1.) The collective stick controls

the total thrust generated by the main rotor. Therefore, it generally controls the vertical motion of the helicopter.

31. Although the above description of helicopter controls is representative, some helicopters may combine the cyclic stick and pedals into a single three-axis stick (movement forward and backwards, left and right, and rotational). Others may combine the cyclic stick, collective stick, and pedals into a single four-axis stick (movement forward and backwards, left and right, up and down, and rotational). Alternatively, others may separate the functionality of the cyclic stick into two sticks. All of these configurations are known configurations for helicopter controls.

2. Sensors

32. Helicopters are equipped with a range of sensors to provide pilots and flight control systems with the measurements and information necessary to safely complete their missions. These sensors include Inertial Measurement Units (IMUs), GPS, Pitot tubes, altitude sensors, radar, as well as other advanced sensor systems.

33. IMUs are typically a combination of gyroscopes and accelerometers that provide measurements for attitude, attitude rate, relative velocity, and position. They also sometimes include magnetometers, which measure orientation relative to

the Earth's magnetic field. The raw outputs of the gyroscopes, accelerometers, and magnetometer are processed (via filtering and sensor fusion) to give the more useful measurements of aircraft states like pitch, roll, and yaw angles, as well as relative velocity and position.

34. Pitot tubes, which measure fluid velocity, are used to provide airspeed measurements, like in fixed-wing aircraft. For helicopters, these devices are typically used for longitudinal velocity measurements (DJI-1023, 30-35.)

35. GPS is used for position measurements, from which velocity and heading can be estimated. The accuracy and error depend on civilian versus military grade GPS. GPS and IMU outputs can be combined via sensor fusion to provide better position and velocity estimates, as well as to allow for absolute position to be determined correcting for any error in measurement from the IMU accelerometers. IMU and GPS sensors can be packaged as integrated systems.

36. Altitude is measured using a combination of barometric altimeters, which measure static pressure, and temperature sensors. At low altitudes, radar can also be used to obtain more accurate measurements (DJI-1020, 125). Modern helicopters may also be equipped with Air Data Computers (ADCs) that combine measurements from Pitot tubes, altimeters, and other sensors to estimate or calculate true and calibrated air speed, altitude, and other air and flight parameters.

3. Actuators and Control Surfaces

37. The pilot commands issued through the pilot's controller (e.g., cyclic stick, collective stick, and foot pedals) are applied to control surfaces including the main and tail rotors through actuators or servos. The actuators move the control surfaces based on the received commands. In modern digital fly-by-wire flight control systems, the pilot commands are monitored by a flight computer which then issues commands to actuators to move the control surfaces.

38. These actuators move the various control surfaces of the aircraft that change the collective or cyclic pitch of the rotor blades. One common control surface is a swash plate which transmits control inputs to the main rotor blades. (DJI-1015, 5-5.) For example, a "stationary swash plate is mounted around the main rotor mast." (DJI-1015, 5-6.) While it is restrained from rotating, it is able to tilt in all directions and move vertically through use of a series of pushrods. (DJI-1015, 5-6.) In older helicopters, these systems may have included mechanical linkages and/or hydraulic boost actuators directly connected to the control surfaces.

39. The collective pitch of the tail rotor is changed using a "pitch change mechanism on the tail rotor gearbox." (DJI-1015, 4-3.) The exact composition of this mechanism and the servo actuator supplying power (e.g. hydraulic vs. electromechanical) likely varies between helicopters, although a linear hydraulic

actuator is often used. The same principle used to change the collective pitch of the main rotor can be applied to the tail rotor as illustrated in the following figure.

(DJI-1015, 4-1.)



Figure 4-1. Raising the collective pitch control increases the pitch angle the same amount on all blades.

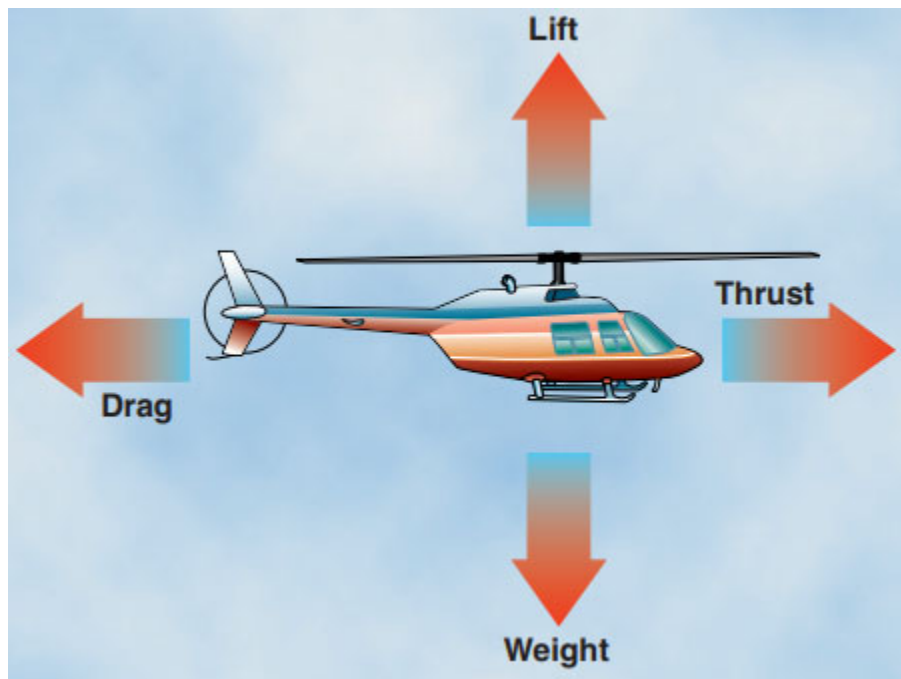
Rotorcraft Flying Handbook, Figure 4-1

40. Actuators can include servo-control valves for hydraulic systems or linear and rotary electromechanical actuators that may consist of brushless DC motors or stepper motors as well as position feedback sensors (which combined with a motor are often referred to as servos). Additionally, these actuators may not directly apply forces to the control surfaces, but instead apply forces through

linkages or other mechanisms to achieve the necessary mechanical advantage and motion profiles.

4. Aircraft Movement

41. Four primary forces (lift, weight, thrust, and drag) act on a helicopter during flight, as illustrated in the figure below. Lift is an upward force; weight opposes lift and is caused by the downward pull of gravity. Thrust propels the helicopter through the air. Drag opposes motion in all directions. Unlike fixed-wing aircraft, the main rotor blades provide lift without requiring the aircraft to move forward.

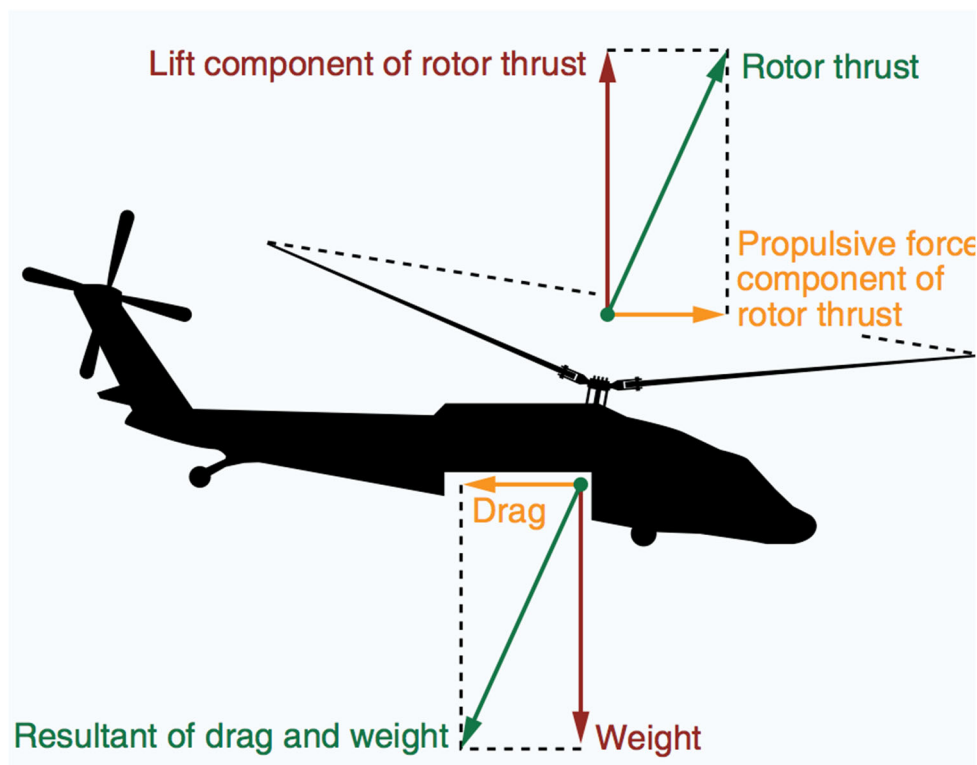


Rotorcraft Flying Handbook, Figure 2-1

42. The basic flight conditions for a helicopter include hover, forward flight, sideward flight, and rearward flight. During hover, a helicopter maintains a constant position over a selected point. (DJI-1015, 3-1.) To hover, the lift and thrust produced by the rotor system collectively act and must equal the weight and drag. Increasing the angle of attack of the rotor blades while their velocity remains constant generates vertical lift and thrust and the helicopter ascends. (DJI-1015, 3-1.) Decreasing the pitch causes the helicopter to descend. (DJI-1015, 3-4.)

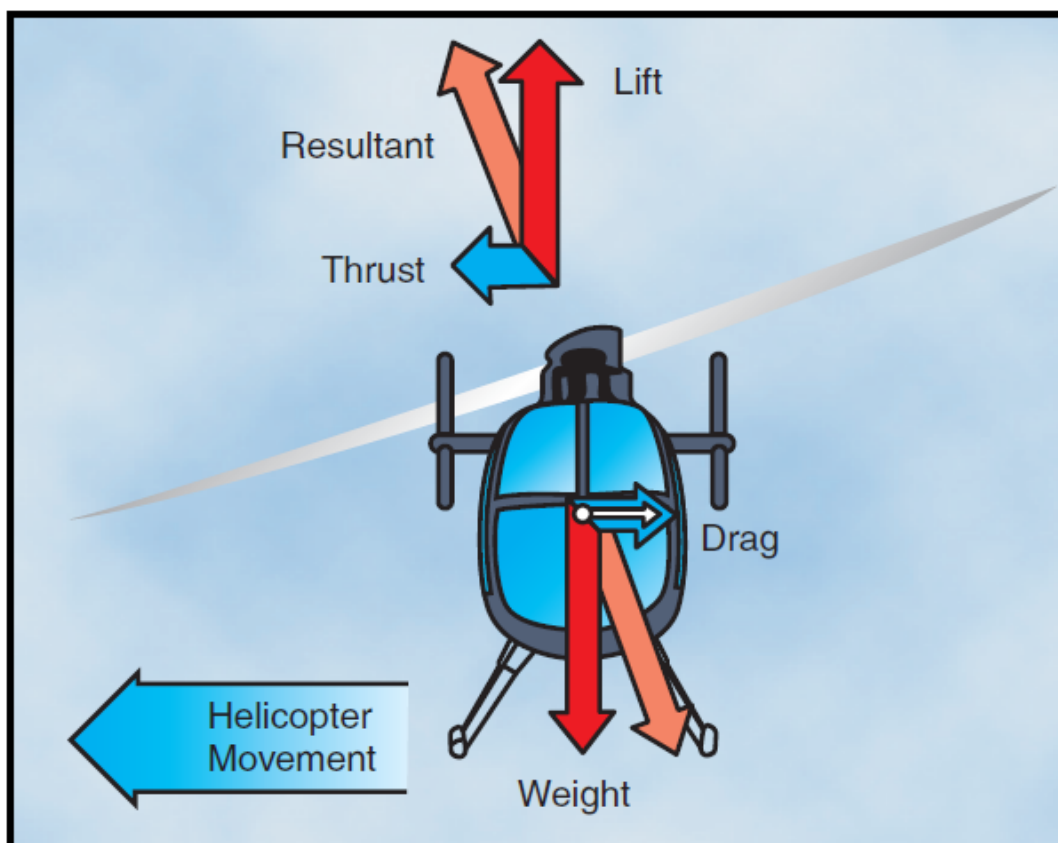
43. A hovering turn is a maneuver performed at hovering altitude in which the nose of the helicopter is rotated either left or right while maintaining position over a reference point on the surface. (DJI-1015, 9-6.) To initiate the turn, the pilot generally applies pedal pressure toward the desired direction. (DJI-1015, 9-6.)

44. As illustrated in the following figure, during forward flight, the tip-path plane is tilted forward, tilting the total lift-thrust force forward from the vertical. (DJI-1015, 3-5.) This force is resolved into lift acting vertically upward and thrust acting horizontally in the direction of flight. As the helicopter moves forward, it begins to lose altitude because of the lift that is lost as the main rotor forces are diverted toward the horizontal direction. (DJI-1015, 3-5.)



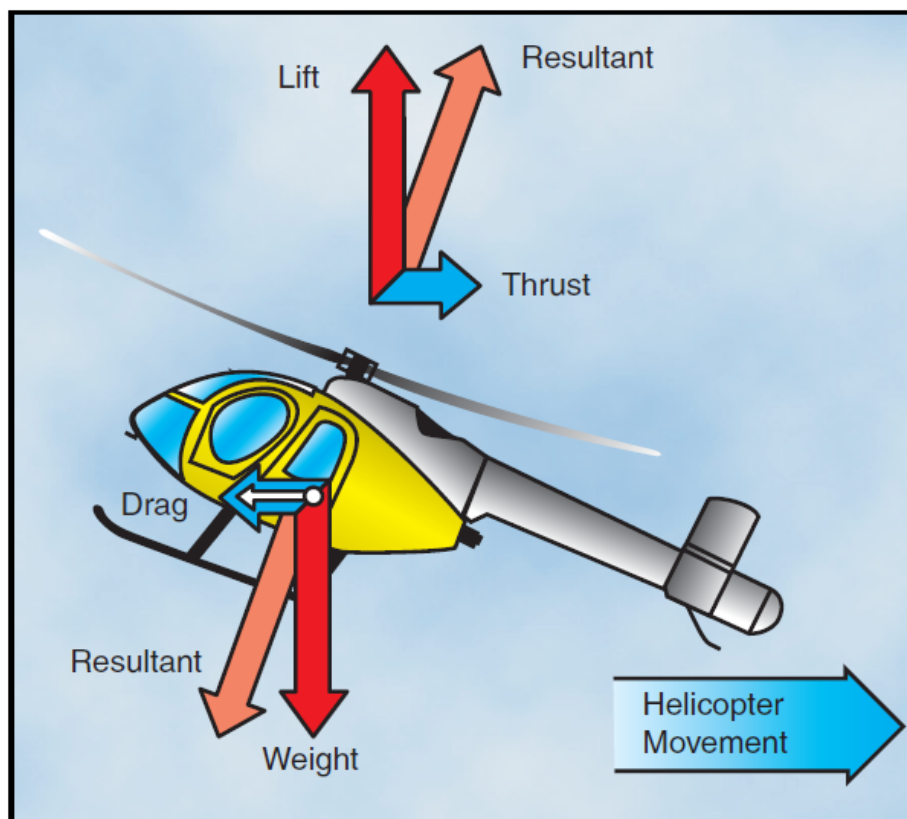
Helicopter Flying Handbook, Figure 2-3 p. 2-2

45. During sideward flight, the tip-path plane is tilted in the direction that flight is desired. (DJI-1015, 3-8.) This action tilts the total lift-thrust vector sideward. (DJI-1015, 3-8.) The vertical or lift component is still straight up and weight straight down (as illustrated below), but the horizontal or thrust component acting sideways, with drag acting in the opposite direction. (DJI-1015, 3-8.)



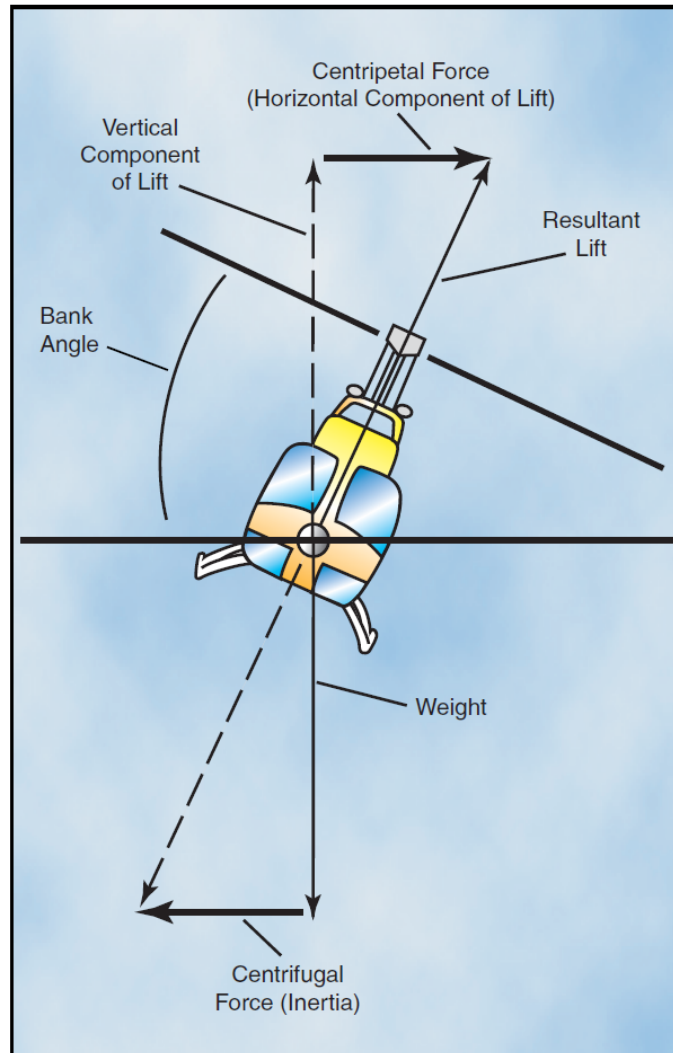
Rotorcraft Flying Handbook, Figure 3-17

46. During rearward flight, the tip-path plane is tilted rearward, which, in turn, tilts the lift-thrust vector rearward. (DJI-1015, 3-8.) Drag acts forward with the lift component straight up and weight straight down as shown below.



Rotorcraft Flying Handbook, Figure 3-18

47. When the helicopter is banked as shown in the figure below, the rotor disc is tilted sideward, thereby resulting in lift being separated into two components. (DJI-1015, 3-8.) As angle of bank increases, total lift force is tilted more toward the horizontal, causing the rate of turn to increase because more main rotor force acts horizontally. (DJI-1015, 3-8.) To compensate for decreased vertical lift, the angle of attack of the rotor blades must be increased to maintain altitude. (DJI-1015, 3-8.) The steeper the angle of bank, the greater the angle of attack required to maintain altitude. (DJI-1015, 3-8.)



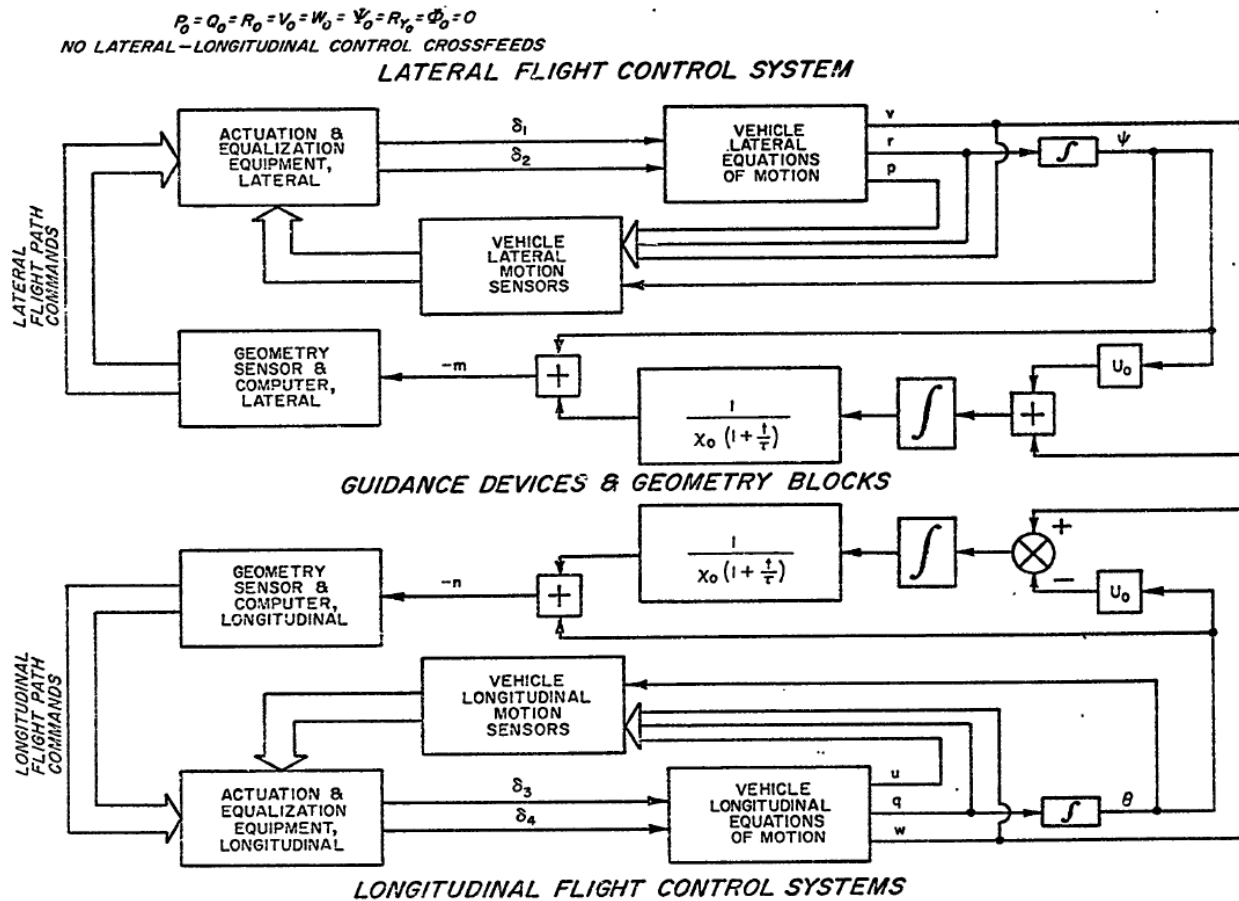
Rotorcraft Flying Handbook, Figure 3-19.

5. Flight Control Systems

48. The control of helicopters is a complicated task because the machines have unusual dynamics and are operated in a wide variety of conditions that range from hovering in place to fast forward flight. Most modern helicopters include a computer-based flight control system. In these systems, pilot commands are

translated by an algorithm, comprised of a set of control laws, into commands to the aircraft's actuators to move the aircraft in the desired manner.

49. Modern control systems use a control architecture that depends on the dynamic model of the system being controlled. Helicopter dynamics models are sets of equations that describe the motion and aerodynamics of the helicopter, its rotor(s), and other components. The equations of motion for a helicopter are derived by summing the force and moment contributions of various structural components of the helicopter (e.g., main rotor, tail rotor, and fuselage). For the design of a flight control system, it was (and remains) common to use linearized equations of motion to describe the vehicle's dynamics near a prescribed operating point in the flight envelope. As shown in the figure below from "Aircraft Dynamics and Automatic Control" (1973) an exemplary control system for an aircraft includes a lateral control component utilizing lateral equations of motion and a longitudinal control component utilizing longitudinal equations of motion (described further below). (DJI-1017, 16.) I discuss the models and the aircraft equations of motion in further detail below.



McRuer (1973), Figure 1-4

50. Helicopters can have different operational modes, also referred to as response types, for different flight conditions. The response type determines how the helicopter responds to a given pilot input. Therefore, the helicopter response to a given pilot input depends on the design of the flight control laws. Common response types used for hovering are Attitude Command/Attitude Hold (ACAH), which will also typically include use of an Altitude or Height Hold (HH), and Translational Rate Command (TRC), which can include an inner loop ACAH. For

forward flight, typical response types include Attitude Command/Velocity Hold (ACVH), Rate Command/Attitude Hold (RCAH), and Yaw Rate Command/Direction (Heading) Hold (RCDH). Turn Coordination (TC) may also be included, which is used, for example, to keep the aircraft heading aligned with the flight direction during banked turns in response to lateral pilot inputs.

a. Model

51. Helicopter dynamic models are used for simulation studies during the design of the helicopter and its flight controller. Furthermore, many modern flight controllers can be considered model-based controllers in the sense that the model equations of motion may be directly used as part of the control law (this can include real-time simulation of a model to generate reference commands). Alternatively, the model may be used as part of the calculation of controller gains or other parameters (e.g., using an optimal control formulation). These systems are referred to as model-following control systems.

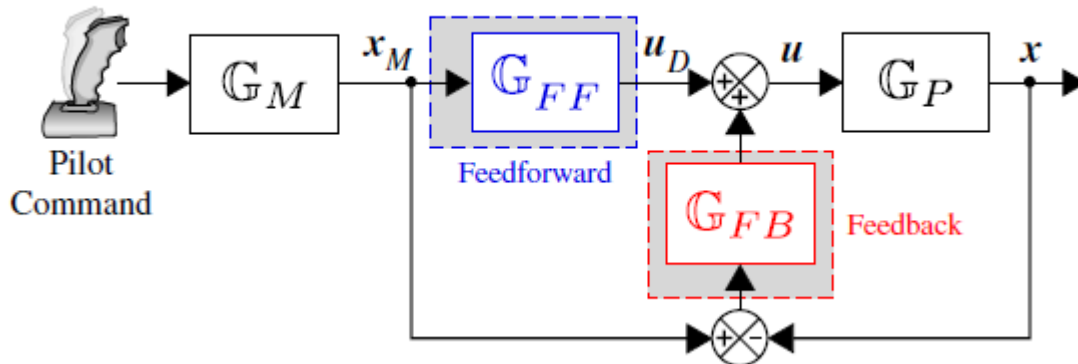
52. In the paper, “The Characteristics of Model-Following Systems as Synthesized by Optimal Control” published in October 1964 by the IEEE, Tyler discusses two types of model-following systems and their application to aircraft flight control: model-in-the performance index and model-in-the-system. (DJI-1021, 486.) The model-in-the performance index technique “uses the feedback

gains generated by the optimal-control theory to alter the open-loop plant coefficients such that they approach the coefficients of the model.” (DJI-1021, 486.) The model in this technique “is included only in the quadratic performance index, not in the physical system.” (DJI-1021, 486.) This technique is commonly referred to as “implicit model following.” The model-in-the performance index technique was first developed by Kalman in the early 1960’s, nearly **half a century** before the earliest priority date of the ’082 patent. (DJI-1021, 486, 498.)

53. In contrast, in the model-in-the-system technique, “the model is included in the physical system as a pre-filter ahead of plant.” (DJI-1021, 489.) As explained by Tyler, the resulting system “has not only feedback gains for the plant state variables but also feedforward gains for the model state variables.” (DJI-1021, 485.) This technique is commonly referred to as explicit model following. As noted by Tyler, the model-in-the-system technique was used by Kalman in the early 1960’s, nearly **half a century** before the earliest priority date of the ’082 patent. (DJI-1021, 486, 498.) I note that Tyler decoupled the lateral and longitudinal equations of motion for the aircraft and applied the model-in-the-system technique to both motion directions separately. (DJI-1021, 494-496.)

54. Explicit model following controllers make use of the model of a helicopter’s plant dynamics as part of the control system and is a common control

architecture in the helicopter community. In an explicit model following controller, the pilot command is used as input to a prescribed model G_M which is sometimes referred to as the command model. (See DJI-1022, 98.) The rest of the control system is designed to force the output of the helicopter plant, G_P , to track the prescribed model output, x_M . (DJI-1022, 98.) Feedback, G_{FB} , determines the error dynamics of the model tracking. (DJI-1022, 98.) Feedforward control G_{FF} is selected to cancel undesired helicopter dynamics using model inversion techniques and is often referred to as an inverse model. (DJI-1022, 98.)



Adams/Singhose (DJI-1022), Figure 6

b. Equations of Motion

55. The equations of motion for a helicopter are derived by summing the force and moment contributions of various structural components of the aircraft. The dynamic response of an aircraft has three translational degrees of freedom, three rotational degrees of freedom, and “more elastic degrees of freedom than one

would care to count.” (DJI-1019, 720.) Assuming an aircraft to be a rigid body, reduces the problem to one of six degrees of freedom. (DJI-1019, 720.) This means the aircraft has six directions of motion that it can follow: it can move forward, backward, sideways, and up-down; and it can rotate about its axes with yaw, pitch, and roll. To solve for these six degrees of freedom, six simultaneous equations are necessary—these are known as the aircraft equations of motion.

56. The equations of motion are generally derived from Newton’s second law of motion, which describes the aircraft with respect to its three translational degrees of freedom and three rotational degrees of freedom. The force equations can be expressed as:

$$F_x = \frac{d}{dt} (mu) \quad F_y = \frac{d}{dt} (mv) \quad F_z = \frac{d}{dt} (mw)$$

where F_x , F_y , F_z and u , v , w are the components of the force and velocity along the x , y , and z axes, respectively. The moment equations can be expressed in a similar manner:

$$L = \frac{d}{dt} H_x \quad M = \frac{d}{dt} H_y \quad N = \frac{d}{dt} H_z$$

where L , M , N and H_x , H_y , H_z are the components of the moment and moment of momentum along the x , y , and z axes, respectively. These equations of motion are nonlinear. (DJI-1019, 638.)

57. When motion of the aircraft is confined to small deviations from steady equilibrium flight, the equations of motion can be linearized. (DJI-1019, 720; DJI-1018, 104.) These linearized equations of motions can be separated into linearized longitudinal equations and linearized lateral equations. (DJI-1019, 720.) For small deviations from equilibrium, “no coupling exists between the longitudinal motion and the lateral motion.” (DJI-1019, 720.) This allows each set of equations to be solved independently. (DJI-1019, 720-721.) The following table sets forth the longitudinal equations of motion and the lateral equations of motion.

TABLE 3.2

The linearized small-disturbance longitudinal and lateral rigid body equation of motion

Longitudinal equations	
$\left(\frac{d}{dt} - X_u\right) \Delta u - X_w \Delta w + (g \cos \theta_0) \Delta \theta = X_{\delta_e} \Delta \delta_e + X_{\delta_r} \Delta \delta_r$	
$-Z_u \Delta u + \left[(1 - Z_w) \frac{d}{dt} - Z_w\right] \Delta w - \left[(u_0 + Z_q) \frac{d}{dt} - g \sin \theta_0\right] \Delta \theta = Z_{\delta_e} \Delta \delta_e + Z_{\delta_r} \Delta \delta_r$	
$-M_u \Delta u - \left(M_w \frac{d}{dt} + M_w\right) \Delta w + \left(\frac{d^2}{dt^2} - M_q \frac{d}{dt}\right) \Delta \theta = M_{\delta_e} \Delta \delta_e + M_{\delta_r} \Delta \delta_r$	
Lateral equations	
$\left(\frac{d}{dt} - Y_v\right) \Delta v - Y_p \Delta p + (u_0 - Y_r) \Delta r - (g \cos \theta_0) \Delta \phi = Y_{\delta_r} \Delta \delta_r$	
$-L_v \Delta v + \left(\frac{d}{dt} - L_p\right) \Delta p - \left(\frac{I_{yz}}{I_x} \frac{d}{dt} + L_r\right) \Delta r = L_{\delta_a} \Delta \delta_a + L_{\delta_r} \Delta \delta_r$	
$-N_v \Delta v - \left(\frac{I_{xz}}{I_z} \frac{d}{dt} + N_p\right) \Delta p + \left(\frac{d}{dt} - N_r\right) \Delta r = N_{\delta_a} \Delta \delta_a + N_{\delta_r} \Delta \delta_r$	

(DJI-1018, 108; *see also*, DJI-1019, 647.)

c. Coordinate Systems

58. The degrees of freedom of an aircraft model depend on the reference coordinate system used in the model formulation. Body-fixed coordinate systems are common. The body-fixed coordinate system has the origin located at the aircraft center of gravity, as shown below. (DJI-1019, 602.) For Earth-fixed coordinate systems, the x-y plane is usually normal to the local gravitational vector with the x-axis pointing north and the y-axis pointing east. (DJI-1019, 602.) These two types of coordinate systems are illustrated in the figure below.

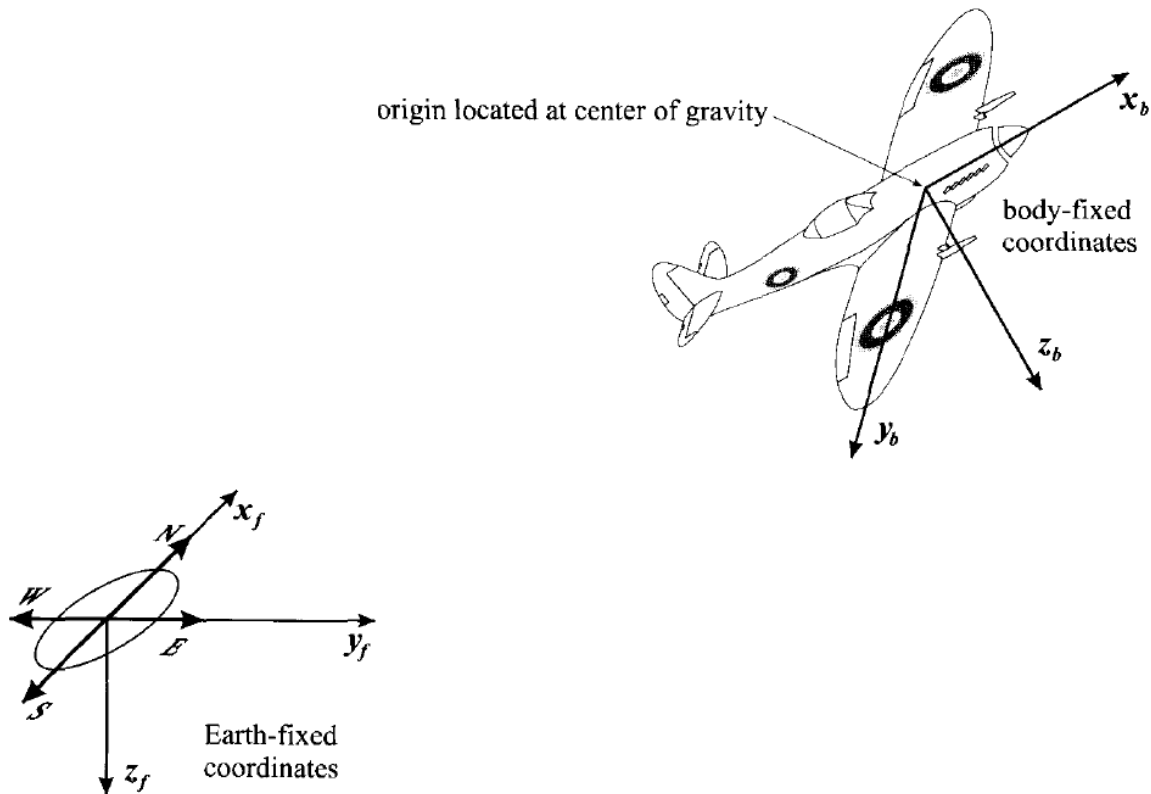


Figure 7.1.2. The body-fixed and Earth-fixed coordinate systems.

6. Navigation

59. Navigation focuses on controlling the movement of a vehicle from one place to another. In this section, I address several components of navigation. The **heading** of an aircraft is the direction in which the nose of the aircraft points during flight. (DJI-1016, 1-6.) The aircraft's actual projected path over the ground, which is a combination of wind and the motion of the aircraft relative to wind, is called the **ground track**. Ground track is sometimes referred to as a **course**. The heading of an aircraft may be significantly different from the ground track due to wind. The angle between the heading and the ground track is called the drift angle as shown in the figure below.

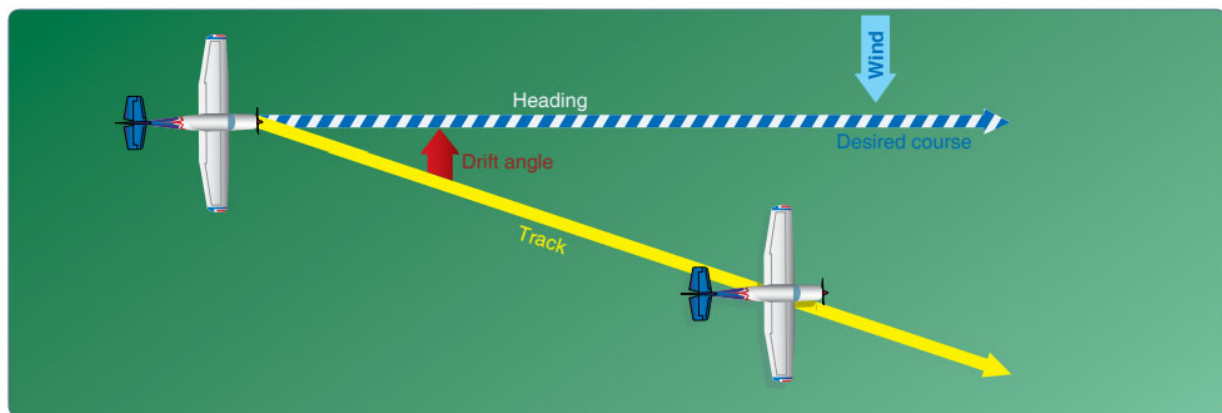


Figure 16-15. Effects of wind drift on maintaining desired course.

60. The airspeed is the rate of the aircraft's progress through the air. The groundspeed is the rate of the aircraft's progress over the ground. For example, as shown in the following figure, an aircraft flying eastward at an airspeed of 120

knots in still air has a groundspeed of 120 knots. If the mass of air is moving eastward at 20 knots, then the airspeed of the aircraft is not affected but the progress over the ground is 120 plus 20 or 140 knots (groundspeed). If the mass of air is moving westward at 20 knots, then the airspeed of the aircraft remains the same, but the groundspeed becomes 120 minus 20 or 100 knots (groundspeed).

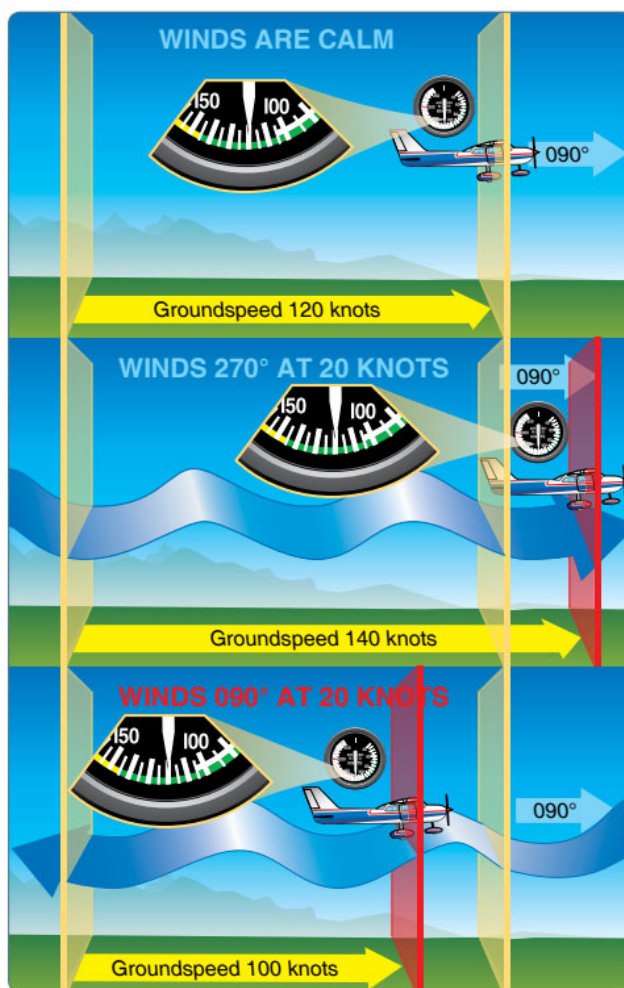


Figure 16-13. Motion of the air affects the speed with which aircraft move over the Earth's surface. Airspeed, the rate at which an aircraft moves through the air, is not affected by air motion.

Pilot's Handbook of Aeronautical Knowledge, Figure 16-13
(available at

https://www.faa.gov/regulations_policies/handbooks_manuals/aviation/phak)

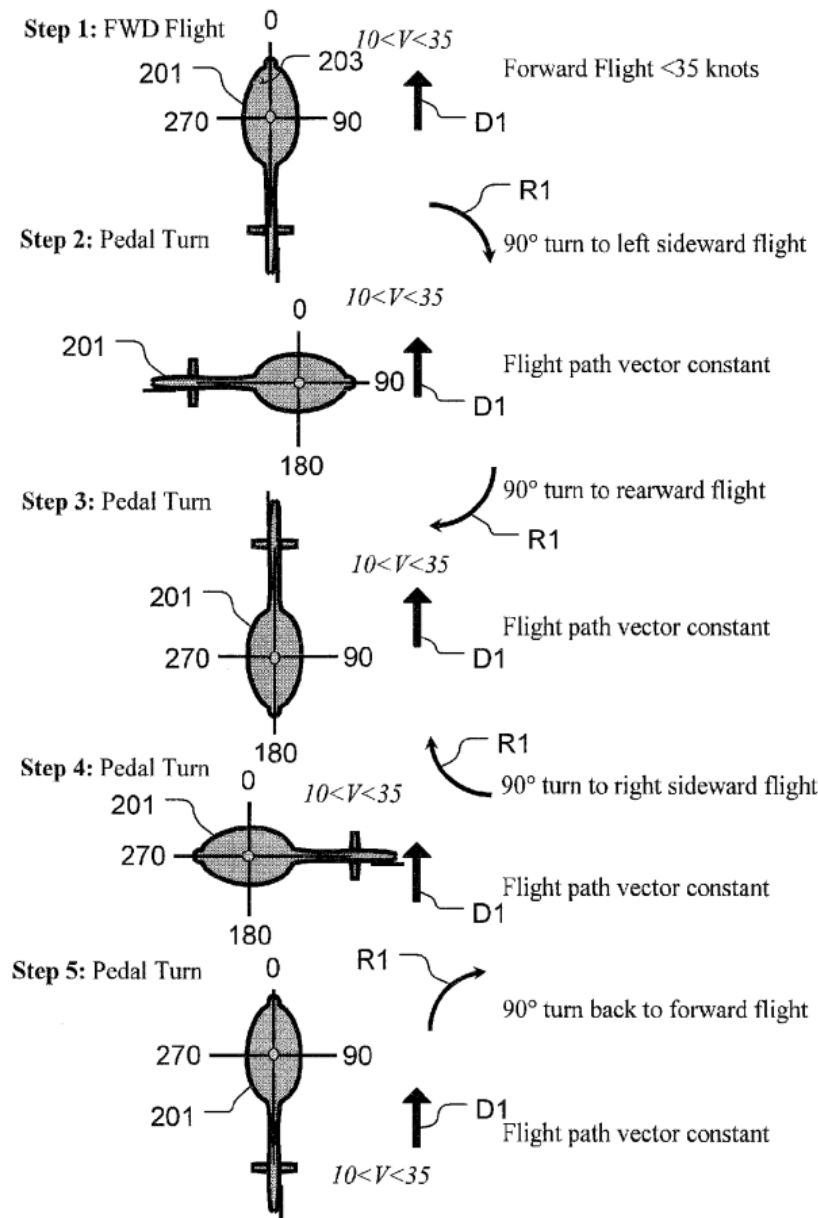
61. When an aircraft is pointed in one direction but moving in another direction, it is said to “crab.” The crab angle is the amount an aircraft must be turned into the wind in order to maintain the desired course. It is equal in

magnitude but opposite in direction to the drift angle. A crab technique is often used to correct for crosswind conditions during landing.

B. Overview of the '082 Patent

62. U.S. Patent 8,332,082 was filed as PCT/US2011/030498 on March 30, 2011. Accordingly, for purposes of this IPR proceeding, I have used March 30, 2011 as the earliest possible priority date for the '082 patent.

63. The '082 patent claims an aircraft control system that controls the yaw rotation of the aircraft while the aircraft maintains a constant velocity flight path relative to the ground surface. (DJI-1001, Abstract.) Such aircraft motion is illustrated in Figure 2 of the 082 patent, which has been reproduced below. This figure illustrates a helicopter with a flight path in the D1 direction (toward the top of the page). Directional inputs from the pilot turn the aircraft “in a complete 360 degree yaw movement R1, stopping every 90 degrees, and without changing the speed and flight heading” of the aircraft. (DJI-1001, 3:2-5.) The motion represented in Figure 2 of the '082 patent indicates that the aircraft rotates about its vertical axis in a yaw motion, while simultaneously, the body of the aircraft travels in a constant velocity (straight line) relative to the ground surface. That is, the aircraft maintains its **course** (ground track) D1.



'082 Patent, Figure 2

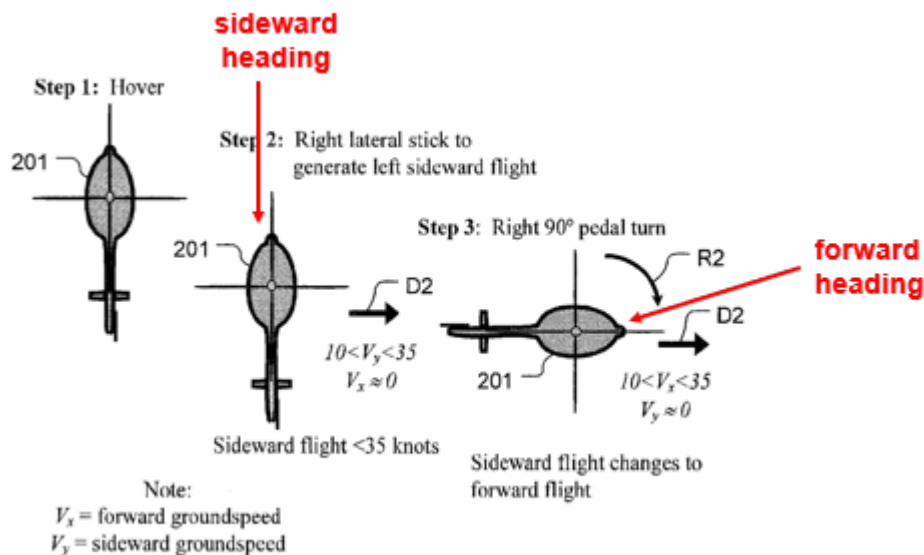
64. The text used to describe Figure 2 is inconsistent with the pictorial representation. The text states that “[d]irectional inputs turn aircraft 201 in a complete 360 degree yaw movement.” (DJI-1001, 3:2-3.) This means that the

maneuver illustrated in Figure 2 **changes the heading of the aircraft** through a complete 360 degree rotation. However, the text goes on to state that the maneuver is performed “**without changing the...flight heading of aircraft**² 201.” (DJI-1001, 3:4-5.) A POSITA would understand that “heading” is the direction the nose of the aircraft is pointing. A POSITA would also understand that the path the aircraft body is following, relative to the ground, is the “**course**” or “**ground track**.” Therefore, a POSITA would know that the description of Figure 2 should say that the 360° yaw rotation is performed without changing the speed and flight **ground track** of the aircraft.

65. The '082 patent does use the term “heading” consistently with its well understood meaning in the art in relation to other figures. In Figure 4 (reproduced below), the '082 patent describes aircraft 201 as changing flight heading from sideward flight to forward flight. In step 2, the aircraft “travel[s] in a sideward groundspeed between 10-35 knots, as depicted with arrow D2.” (DJI-1001, 3:60-62.) A “right lateral control stick (not shown) is utilized to generate a **left sideward heading**.” (DJI-1001, 3:62-63.) This “sideward heading” description is correct because the nose of the aircraft is turned 90° sideways relative to the

² Unless otherwise indicating, all emphasis by bold added.

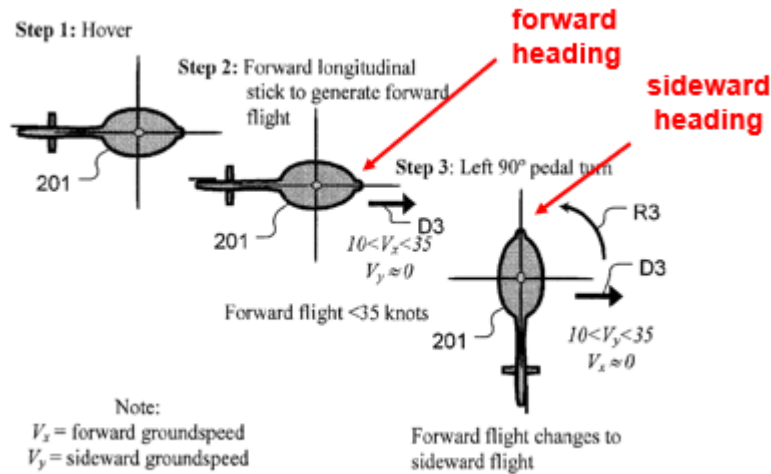
direction of travel (the course). A right 90° pedal turn “rotate[s] aircraft 201 in a **forward heading** with a petal 203.” (DJI-1001, 3:64-65.) This “forward heading” description is correct because the nose of the aircraft is pointing forward relative to the course being traveling by the aircraft.



'082 Patent, Figure 4

66. Like Figure 4, the '082 patent uses the term “heading” consistently with its understood meaning in the art in its description of Figure 5. In Figure 5, which is reproduced below, the control system turns the aircraft “from a forward groundspeed V_x between 10-35 knots and a sideward groundspeed of about 0 knots to a sideward groundspeed between 10-35 knots and a forward groundspeed about 0 knots.” (DJI-1001, 4:9-14.) In step 2, the aircraft “travel[s] in a forward heading” as depicted with arrow D3. (DJI-1001, 4:15-16.) In this step, “a forward

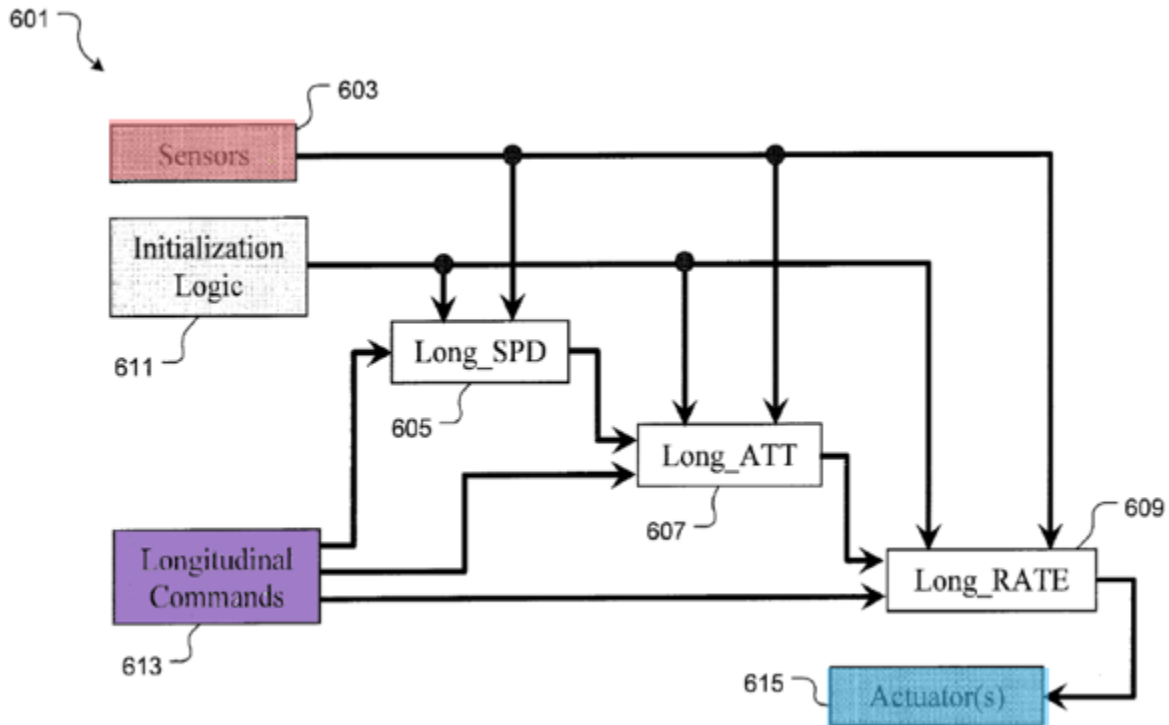
longitudinal stick is utilized to generate forward flight.” (DJI-1001, 4:17-18.) A left 90° petal turn “is applied to rotate” the aircraft “such that the forward flight of aircraft 201 changes to a **sideward flight heading**.” (DJI-1001, 4:18-21.)



'082 Patent, Figure 5

67. The control system of the '082 patent includes a longitudinal control architecture associated with “one or more longitudinal control laws”, a lateral control architecture associated with “one or more lateral control laws”, and an architecture associated with “one or more directional control laws.” (DJI-1001, 4:35-42.) The longitudinal control architecture 601 is illustrated in Figure 6 below. The longitudinal control architecture includes sensors 603 (shaded red), initialization logic 611 “adapted for determining which loop is active in each axis based on flight conditions and pilot control inputs,” and longitudinal command 613

based on the pilot's control input "in each axis." (DJI-1001, 4:43-45, 5:2-5, 5:9-11.) The inputs to the longitudinal architecture are (1) a command signal from the pilot's controller (e.g., "the difference between the controller's present position and the centered, no force position" (the 'detent' position)) and (2) data from sensors 603. (DJI-1001, 5:11-14.) The longitudinal control laws process the inputs "to generate the appropriate aircraft response commands." (DJI-1001, 5:16-18.) The control system's outputs "are routed to an actuator 615 for each dynamic axis"—main rotor longitudinal swashplate angle (longitudinal axis, main rotor lateral swashplate angle (lateral axis), main rotor collective pitch (vertical axis), and tail rotor collective pitch (directional axis). (DJI-1001, 5:20-26.)

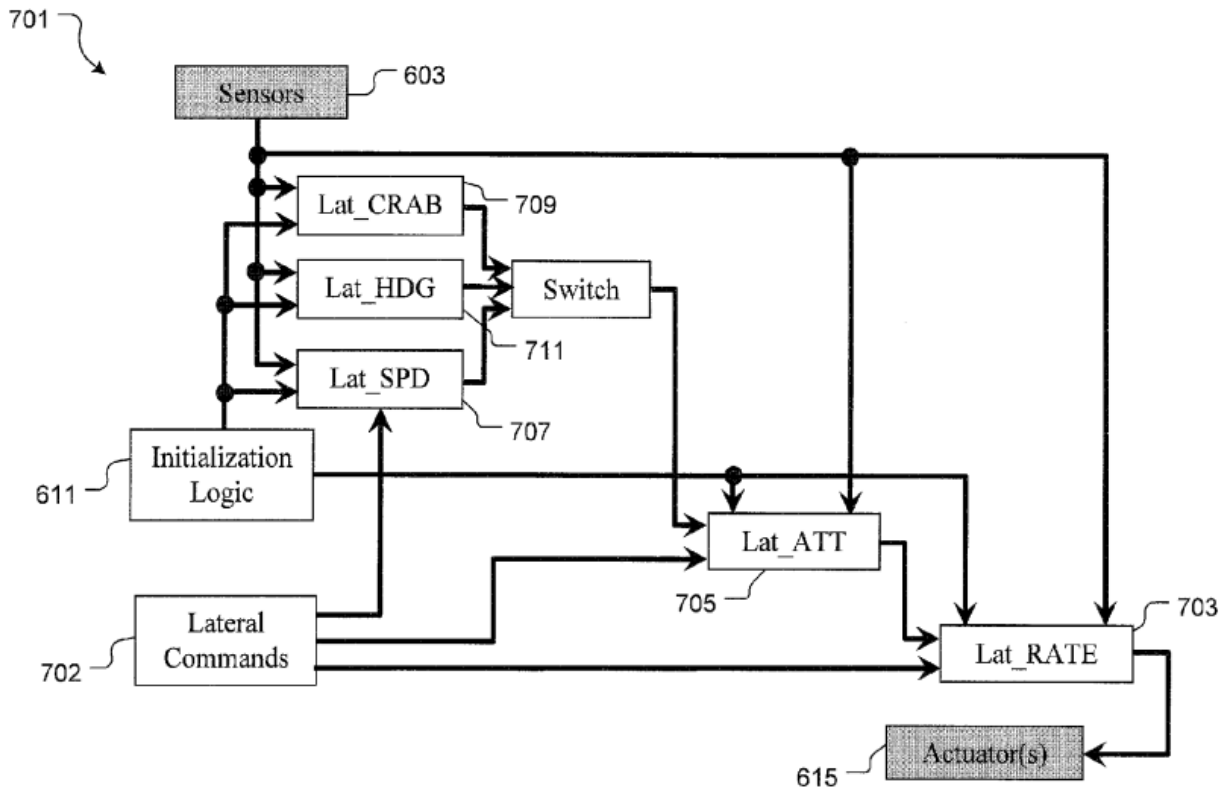


'082 Patent, Figure 6

68. As shown in Figure 6 above, “architecture 601 preferably comprises of [sic] a longitudinal control law for forward speed, represented as block 605 ‘Long_SPD’; a longitudinal control law for pitch angle, represented as block 607 ‘Long_ATT’; and, a longitudinal control law for pitch rate, represented as block 609 ‘Long_RATE’.” (DJI-1001, 4:64-5:2.) When flying with the longitudinal controller in detent and outside of the Hover Hold/TRC region 105, “the Long_SPD 605 loop will be active.” (DJI-1001, 5:33-35.) “At lower speeds, this loop will hold constant forward groundspeed, while at higher speeds, airspeed will be held.” (DJI-1001, 5:35-37.) When the pilot moves the longitudinal controller

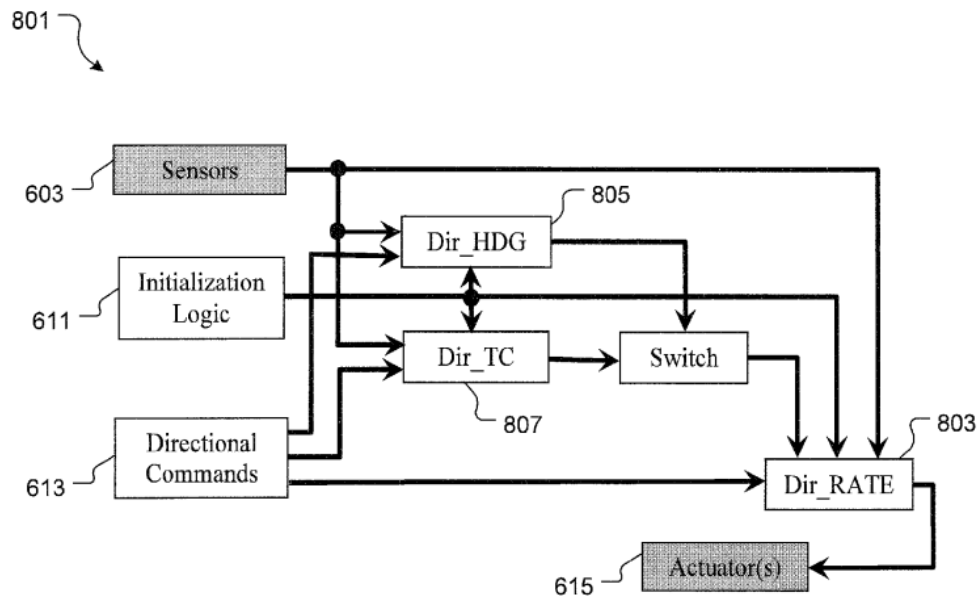
out of detent, “the control laws can command either pitch attitude (Long_ATT 607) or pitch rate (Long_Rate 609).” (DJI-1001, 5:37-40.)

69. The lateral control system architecture 701 is illustrated in Figure 7 below. Architecture 701 includes sensors 603, logic 611, and actuators 615 (which are also included in the longitudinal architecture 601 of Figure 6 as indicated by use of the same labels). “The lateral control laws include: a lateral control of roll rate, represented as block 703 ‘Lat_RATE’; a lateral control of the roll attitude, represented as block 705 ‘Lat_ATT’; a lateral control of sideward groundspeed, represented as block 707 ‘Lat_SPD’; a lateral control of the crab angle, represented as block 709 ‘Lat_CRAB’; and, lateral control of heading, represented as block 711 ‘Lat_HDG’.” (DJI-1001, 5:44-50.)



'082 Patent, Figure 7

70. Directional control architecture 801, illustrated in Figure 8 below, including one or more directional control laws, is also “associated with sensors 603, logic 611, commands 613, and actuators 615.” (DJI-1001, 6:11-14.) The directional control laws include directional control of yaw rate (“Dir_RATE” 803), directional control of heading (“Dir_HDG” 805) and directional turn coordination (“Dir_TC” 807). (DJI-1001, 6:14-18.)



'082 Patent, Figure 8

71. Using the above control architectures, the '082 patent claims a system and method to fly along a constant ground vector, while simultaneously yawing the aircraft.

C. Level of Ordinary Skill in the Art

72. I understand that certain issues relating to the validity of the '082 patent must be judged from the perspective of a person of ordinary skill in the relevant art, as I discuss below. I have been asked to define the level of a “person of ordinary skill in the art” or “POSITA” at the time the alleged invention as claimed was made. In deciding the level of ordinary skill, I have considered the following factors, which I have been informed are relevant to the determination of ordinary skill in the art.

- levels of education and experience of persons working in the field;
- types of problems encountered in the art;
- prior art solutions to these problems;
- rapidity with which innovations are made; and
- sophistication of the technology.

73. In my opinion, a POSITA would have had at least an equivalent of a Bachelor's degree from an accredited institution in mechanical engineering, aerospace engineering, electrical engineering, robotics or any other discipline covering principles of the design or operation of flight controls for helicopters, drones, or other rotary aircraft, as well as one year of experience working on the design, development, implementation, or operation of such technologies. Significant experience could substitute for formal education, and significant additional education could substitute for work experience.

74. I arrived at this definition by considering the various factors listed above. For example, the types of problems encountered in aircraft control include cross coupling of different motions. For example, pitching a helicopter causes forward longitudinal motion, but also causes a coupled, and generally undesired, effect wherein the aircraft losses altitude in the vertical direction. Engineers trained in the above list of disciplines would know how to configure control architectures

to deal with such coupled dynamic effects. Prior art solutions to problems addressed by the '082 patent include decoupling the aircraft dynamics such that a longitudinal controller can primarily address longitudinal motion and a lateral controller can primarily address lateral motion. Such decoupled controllers are often implemented using a reference model. Once again, engineers trained in the above list of disciplines would know how to decouple dynamics and would be familiar with model-reference control. The claimed technology is generally taught in the junior or senior year of engineering programs. The particular arrangement of components claimed in the '082 patent, as well as details of “stick controllers” would not be taught in undergraduate curriculums; therefore, some amount of practical work experience with these issues would be beneficial in understanding and practicing the claimed technology. I was at least a POSITA as of the priority date of the '082 patent because I received an undergraduate degree in mechanical engineering in 1990 and I had worked for many years on the claimed subject matter.

D. Prosecution History

1. U.S. Prosecution (Family)

75. The application leading to the '082 patent was allowed in the first action. (*See* DJI-1002.) I therefore discuss the prosecution of the continuation

patent, U.S. Patent 8,682,505 (“the ’505 patent”), in this section, because the claims of the ’505 patent have limitations which overlap with limitations in the claims of the ’082 patent.

76. The application leading to the ’505 patent was filed with 20 claims. Claims 1 and 11, reproduced below, are the originally filed independent prosecution claims:

[1P] A control system for an aircraft, comprising:

[1A] a lateral control architecture configured to control lateral motion of the aircraft; and

[1B] a longitudinal control architecture configured to control longitudinal motion of the aircraft;

[1C] wherein the control system utilizes the lateral control architecture and the longitudinal control architecture to control yaw movement of the aircraft while the aircraft maintains a constant vector heading across a ground surface.

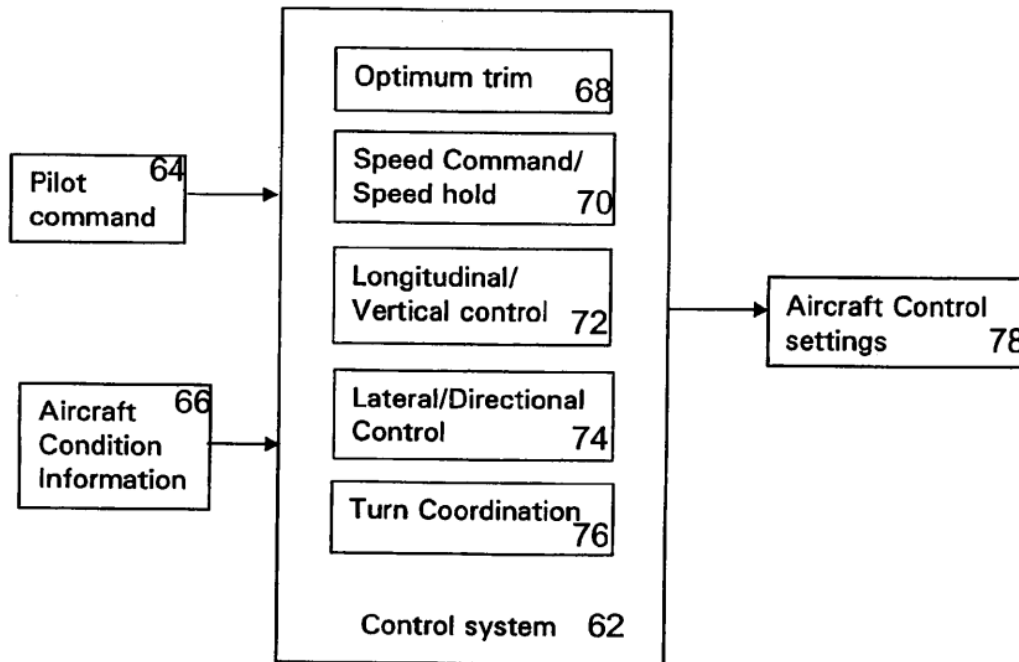
[11P] A method, comprising:

[11A] sensing a directional movement of an aircraft;

[11B] determining lateral and longitudinal movements of the aircraft; and

[11C] selectively controlling flat yaw movement of the aircraft while maintaining a constant vector flat turn relative to a ground surface.

77. The Examiner rejected all originally filed claims as being anticipated by U.S. Patent Publication 2010/0324758 to Piasecki, et al (“Piasecki”; DJI-1013). The Examiner found that Piasecki discloses “at least a lateral control architecture configured to control lateral motion of the aircraft (see at least figure 5 item 74), and longitudinal control architecture configured to control longitudinal motion of the aircraft (see at least figure 5 item 72), wherein the control system utilizes the lateral control architecture and the longitudinal control architecture to control yaw movement of the aircraft while the aircraft maintains a constant vector heading across a ground surface (see at least figures 5-7, 10, 11, and the related text).” (DJI-1025, 38-39; *See* DJI-1013, Figure 5 below.) The Examiner similarly found the remaining claims as anticipated by Piasecki as “shown in at least figures 5-11 and the related text.” (DJI-1025, 39.)



Piasecki, Figure 5

78. In response, Applicant amended independent claims 1 and 11 to add the limitation “*wherein the aircraft continuously moves in a yaw direction while maintaining the constant vector heading.*” (DJI-1025, 23, 25.) Applicant argued that “[a]lthough Piasecki does disclose a system that utilizes lateral and longitudinal motions, the art is silent with respect to using these movements along with maintaining a constant vector heading.” (DJI-1025, 27.) Applicant therefore admitted that systems with lateral and longitudinal control architectures were known which I agree with as discussed in the Background section. Such systems were disclosed, for example, at least 40 years before the earliest possible priority

date of the '082 patent in “Aircraft Dynamics and Automatic Control” by McRuer, et al. (*See* DJI-1017, 16.)

79. The Examiner subsequently allowed the claims based on Applicant’s amendment without further comment. (*See* DJI-1025, 16.) However, the concept of the aircraft controlling yaw turns while maintaining a constant flight path was also known and disclosed by Gold, as I discuss further in §IV.

2. European Prosecution

80. Patent Owner (“PO”) also entered the national stage in Europe from its PCT application. The EP application was originally filed with 20 claims, claim 1 and 11 being the independent claims. I reproduce EP claim 1 below.

1. An aircraft, comprising:

a sensor carried by the aircraft, the sensor being adapted to sense a directional movement of the aircraft;

an actuator carried by the aircraft, the actuator being utilized to control the directional movement of the aircraft; and

a control system in data communication with the aircraft sensor and operably associated with the actuator, the control system having:

a model adapted to decouple the directional movement of the aircraft into a lateral equation of motion and a longitudinal equation of motion;

a lateral control architecture in data communication with the model, the lateral control architecture adapted to utilize the lateral equation of motion to control the lateral motion of the aircraft;

a longitudinal control architecture in data communication with the model, the longitudinal control architecture adapted to utilize the longitudinal equation of motion to control the longitudinal motion of the aircraft; and

an initialization command logic in data communication with the lateral control architecture and in data communication with the longitudinal control architecture;

wherein the initialization command logic selectively activates the lateral control architecture for controlling the lateral motion of the aircraft and selectively activates the longitudinal control architecture for controlling the longitudinal motion of the aircraft; and

wherein the control system utilizes the lateral control architecture and the longitudinal control architecture to control a yaw movement of the aircraft while the aircraft maintains a constant vector heading across a ground surface.

81. The EP Examiner first found that the application lacked support for the following limitation: “wherein the control system utilizes the lateral control architecture and the longitudinal control architecture to control a yaw movement of the aircraft.” (DJI-1012, 143.) The Examiner explained:

However, it is clear from the description that the longitudinal controller and the lateral controller maintain the flight vector over ground constant while the airplane flies with a crab angle > 0 . Control of the “yawing turns” is provided by the directional controller of the helicopter, for example by the pedals in one embodiment of a helicopter (page 4, lines 1-7 and page 12, lines 15-23.)

(Id.)

82. The EP Examiner also found that the independent claims lacked novelty over U.S. Patent 5,553,812 to Gold (“Gold”). (DJI-1012, 143-144.) The Examiner specifically cited to these portions of Gold as disclosing the subject matter of EP independent claim 1: “col. 1 - col. 2, line 22; col. 2, line 65 - col. 3, line 60; col. 4, lines 16-30; col. 5, lines 48-57; col. 6, lines 35-67.” (DJI-1012, 143-144.)

83. In response, Applicant amended the last clause of the independent claims to recite that the control system “utilizes the lateral control architecture and the longitudinal control architecture to maintain a constant vector heading across a ground surface while the aircraft (201) flies with a crab angle greater than zero.” (DJI-1012, 116.) Applicant argued that Gold does not teach or suggest this newly added limitation. (DJI-1012, 140.)

84. The Applicant further amended the specification to acknowledge Gold in the specification of the European application. I reproduce the paragraph added below:

An example velocity command system is described in US 5553812, in which an aircraft flight path referenced velocities are determined with respect to an inertial frame of reference, the flight path referenced velocities are held constant during pilot commanded yaw maneuvers so that **the aircraft maintains a fixed inertial referenced flight path regardless of the pointing direction of the aircraft. Velocity control with respect to an inertial frame of reference is accomplished by controlling the aircraft flight path based on aircraft body referenced commanded lateral and longitudinal acceleration** and based on aircraft body referenced lateral and longitudinal centrifugal acceleration. Operation in the velocity stabilization mode is provided in response to the manual activation of the velocity stabilization mode by the pilot, provided that the aircraft is already operating in the ground speed mode and the aircraft is not in a coordinated turn.

(DJI-1012, 122-123.) This addition to the European patent, especially the portions emphasized above, are an admission by the EP Applicant (PO) that Gold teaches limitations of Claim 1 in the '082 patent.

85. The Examiner maintained the novelty rejection over Gold finding that “maintaining a constant vector heading across a ground surface while the aircraft flies with a crab angle greater than zero is the subject-matter of document D1!” (DJI-1012, 110.) In response, Applicant further amended the independent claim to specify that the lateral control architecture comprises “a lateral sideward groundspeed control loop (707); a lateral roll attitude control loop (705); and a lateral roll rate control loop (703).” (DJI-1012, 93.) Applicant then argued that Gold failed to disclose these features of a “lateral control architecture.” (DJI-1012, 106-108.) In view of this amendment, the EP Examiner allowed the claims.

86. As I establish in §IV.D.2, Gold does disclose these additional limitations added by Applicant to obtain the EP patent.

E. Claim Construction

87. I understand that “claim construction” is the process of determining a patent claim’s meaning. I understand that the Patent Office applies the same claim construction standard used in district courts which seeks to give claim terms their plain and ordinary meaning to a POSITA at the time of the claimed invention in view of the claims, specification, and prosecution history. I also understand that if the patent applicant gave a term a special meaning in the specification or during prosecution, then the special meaning should be used.

88. I do not believe that any terms require explicit construction.

Therefore, I apply the plain and ordinary meaning to the recited claim terms.

IV. GROUND 1: The Combination of Gold, Shue, and Gold-Paper Renders Claims 1-2, 5-6, 8-9, 11-12, 15-16, and 18-19 Obvious.

A. Overview of the Combination

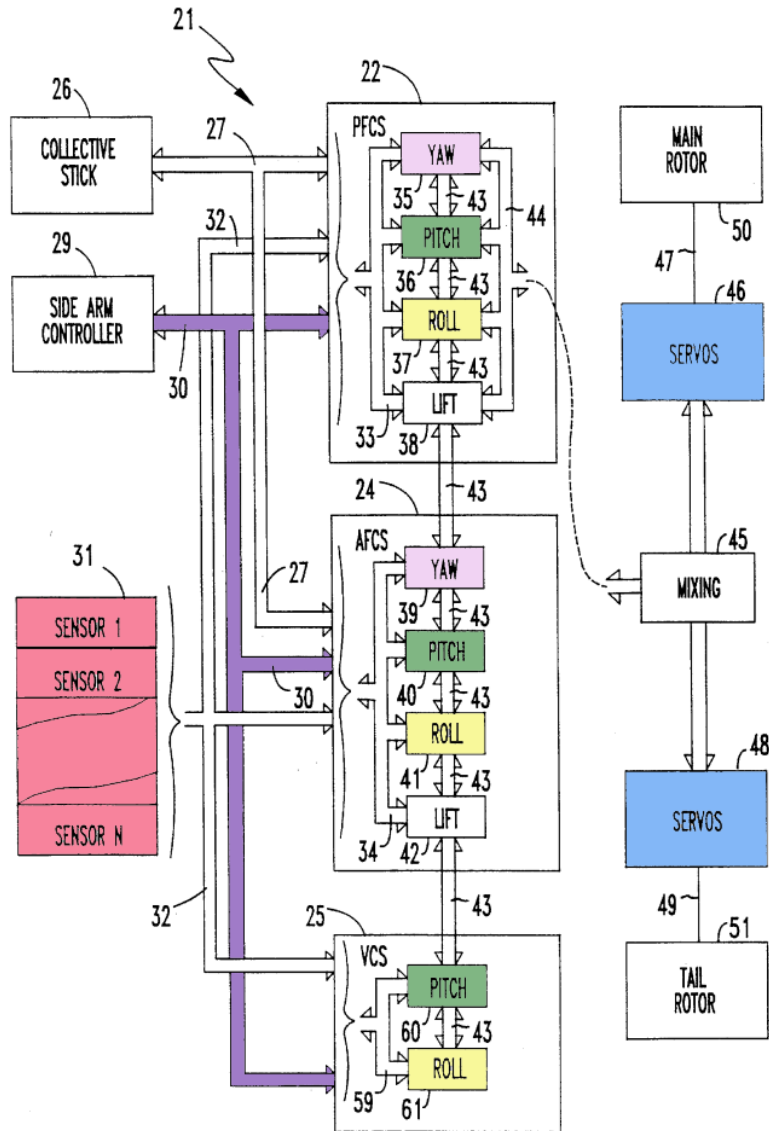
1. Gold

89. U.S. Patent 5,553,812 to Gold, et al (“Gold”) was filed on June 3, 1994 and issued on September 10, 1996, almost 15 years before the earliest possible priority date of the ’082 patent. Gold “relates to aircraft velocity command systems, and more particularly to a velocity command system having an inertial reference which allows a pilot to yaw the aircraft during operation in a velocity stabilization mode without changing the flight path of the aircraft with respect to the inertial reference.” (DJI-1005, 1:9-14.)

90. Gold explains that it was “well known to provide a velocity stabilization mode (velocity hold mode).” (DJI-1005, 1:18-22.) A “pilot may desire to yaw or turn the aircraft while maintaining the velocity hold mode” for example, “to perform a sensor sweep, or for weapons firing.” (DJI-1005, 1:27-31.) However, during operation, “the aircraft flight path will change in response to a pilot yaw input.” (DJI-1005, 1:33-34.) As a result, for such “[c]onventional velocity hold systems,” Gold explains that performing “an inertial reference velocity hold task”

requires “a significant amount of pilot workload.” (DJI-1005, 2:17-22.) To solve this problem, Gold discloses a velocity command system “provided with a velocity stabilization mode.” (DJI-1005, Abstract.) During operation in this velocity stabilization mode, the pilot can “yaw the aircraft from side to side without changing the inertial flight path of the aircraft.” (DJI-1005, 1:51-55.)

91. Gold’s flight control system 21, illustrated below in an annotated version of Gold’s Figure 3, includes primary flight control system (PFCS) 22, automatic flight control system (AFCS) 24 and velocity command system (VCS) 25. (DJI-1005, 3:4-7, Figure 3.) The PFCS and AFCS each contains “control modules for controlling the yaw [shaded pink], pitch [shaded green], roll [shaded yellow] and lift axes of the aircraft.” (DJI-1005, 3:17-20.) The VCS includes a pitch and roll control module.



Gold, Annotated Figure 3

92. The PFCS and AFCS use “a model following algorithm in each control axis to provide rotor command signals” to “rotor mixing function 45 which commands displacement of mechanical servos 46 and linkages 47 to control the tip path plane of a main rotor 50.” (DJI-1005, 3:25-29.) The rotor mixing function 45

also “controls tail rotor servos 48 which control the thrust of a tail rotor 51 through linkages 49.” (DJI-1005, 3:29-32.) Sensed parameter signals from sensors 31 provide the PFCS and AFCS with the aircraft’s angular rate and attitude response to the rotor command signals. (DJI-1005, 3:32-35.) The sensors also “provide information related to velocity, altitude, acceleration, etc.” (DJI-1005, 3:35-36.)

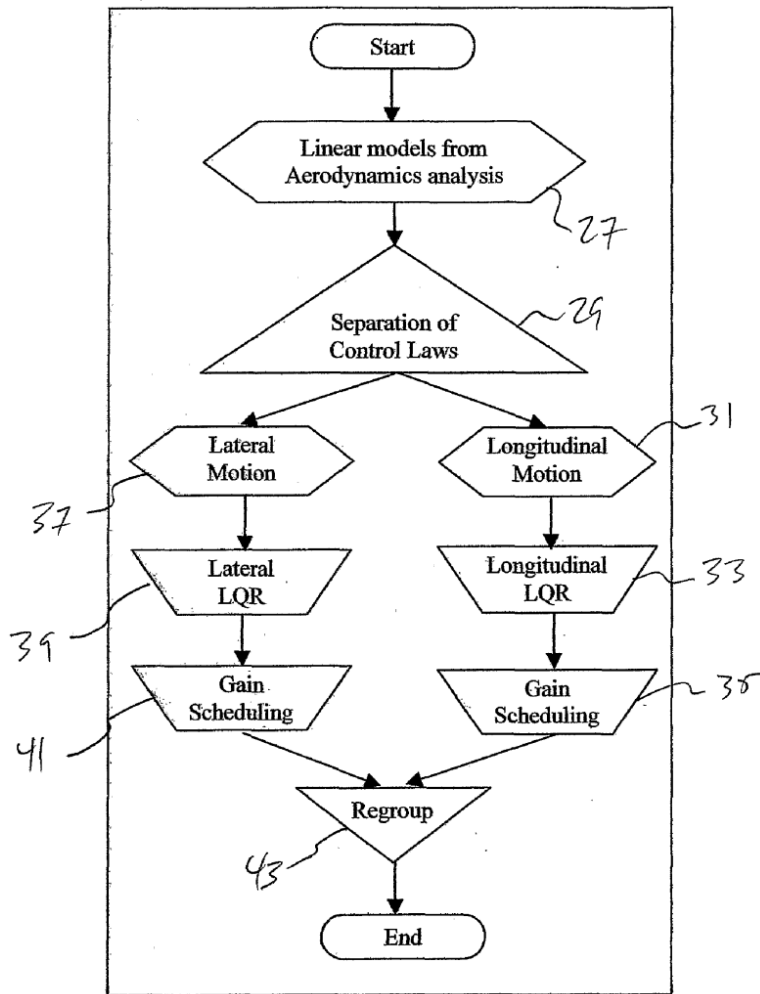
2. Shue

93. U.S. Patent Publication 2008/0097658 to Shue, et al. (“Shue”) published on April 24, 2008, approximately three years before the earliest possible priority date of the ’082 patent. I note that Shue is a co-inventor of the ’082 patent and the Shue patent is assigned to the PO of the ’082 patent.

94. Shue relates “to the field of flight control systems for manned and unmanned aircraft and specifically to systems configured for robustly improving flight performance.” (DJI-1008, ¶1.) In Shue, “[a]ircraft control, guidance, and navigation are implemented by a group of linear models, which are computed from aerodynamic analysis.” (DJI-1008, ¶26.)

95. As illustrated in Shue’s Figure 5 below, the linear models derived from aerodynamics analysis and wind tunnel data (block 27) are separated into longitudinal and lateral control laws as illustrated in block 29 of Figure 5 below. (DJI-1008, ¶40.) In Shue, the longitudinal control laws utilize the longitudinal

equations of motion set forth in Shue's equation (3) and the lateral control laws utilize the lateral equations of motion set forth in Shue's equation (2). (See DJI-1008, ¶¶41, 43.) The longitudinal motion input (block 31) passes to longitudinal linear quadratic regulator (LQR) (control loop) block 33 and the lateral motion input (block 37) passes to lateral LQR (control loop) block 39. (DJI-1008, ¶40.) The objective of LQR state regulation "is to drive any initial condition errors to zero", guaranteeing stability of the system. (DJI-1008, ¶43.) "To achieve this goal, the lateral and longitudinal control inputs, U^{lat} and U^{long} , generated from (2) and (3), apply state feedback control laws" (equations (4) and (5)) to minimize lateral and longitudinal cost functions. (DJI-1008, ¶43.) That is, Shue's decoupled equations (block 29) are used by its lateral and longitudinal control architectures illustrated in Figure 5.



Shue, Figure 5

3. Gold-Paper

96. The paper, “Design and Pilot Evaluation of the RAH-66 Comanche Selectable Control Modes” by Gold, et al. (“Gold-Paper”), discloses the design of control laws for a Comanche helicopter. (DJI-1009, 419.) Like Gold (U.S. Patent 5,553,812), the control system described in the Gold-Paper includes “a Primary Flight Control System (PFCS) and an Automatic Flight Control System (AFCS).”

(DJI-1009, 419.) Both the PFCS and AFCS “use explicit model-following control laws,” like the control system of Gold. (*See* DJI-1009, 419.) The AFCS “consists of both automatic and manually selected modes which allow the pilot to tailor the control system for the existing flight conditions.” (DJI-1009, 419.)

97. Gold-Paper describes a velocity stabilization mode which “is engaged manually by pressing the VEL/HVR HOLD switch on the AFCS control panel.” (DJI-1009, 421.) In this mode, the “roll axis response-type is AC/VH at low speeds, except when in the Hover Hold mode (VC/PH) or when in a low speed coordinated turn (attitude command/attitude hold (AC/AH)).” (DJI-1009, 421.) “The roll response-type **automatically changes modes** from AC/VH to RC/AH [rate command/attitude hold] between 60 and 80 kts.” (DJI-1009, 421; *See* DJI-1009, Figure 2 below.) Hover Hold “engages when groundspeed, pitch and roll rates, longitudinal and lateral linear accelerations, and pitch and roll stick commands are small.” (DJI-1009, 421.) The various response types/modes are shown, as a function of aircraft velocity, in Gold-Paper Figure 2, which has been reproduced below for convenience.

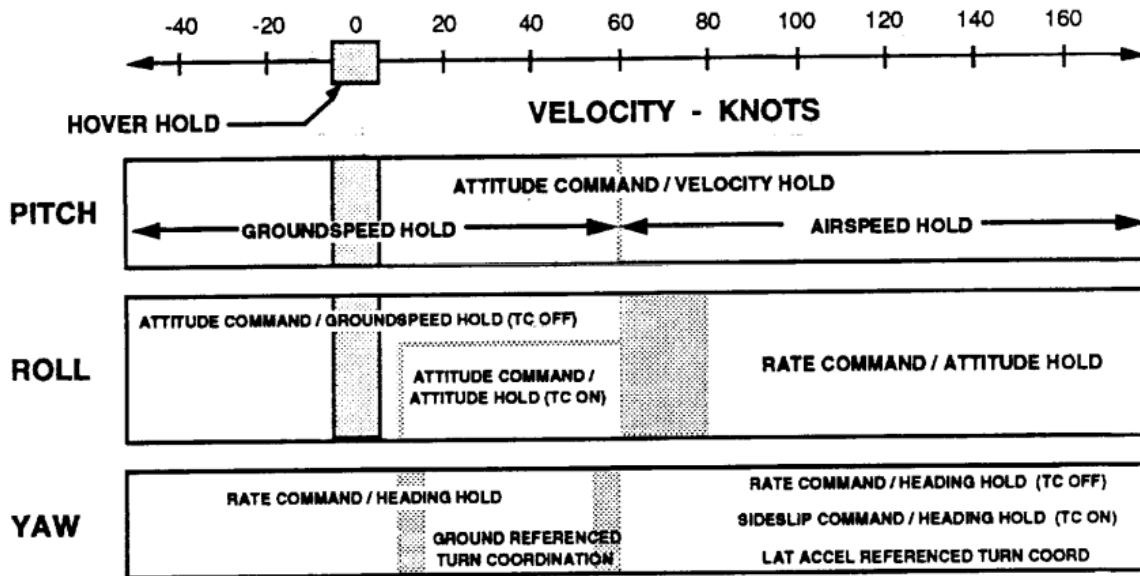


FIGURE 2. VELSTAB CHARACTERISTICS vs VELOCITY

98. Further, while in velocity stabilization mode, “the yaw axis control laws provide automatic low speed turn coordination (LSTC) which is enabled above 15 kts groundspeed.” (DJI-1009, 423.) Altitude Hold mode “engages automatically” when in velocity stabilization mode and Hover Hold mode is entered. (DJI-1009, 423.) In the Altitude Hold mode, “[t]he response-type of the control laws is vertical rate command/altitude (height) hold (RC/HH).” (DJI-1009, 424.)

4. Motivation to Combine

a. Motivation to Combine Gold and Shue

99. A POSITA would have been motivated to combine Shue’s teachings regarding decoupling an aircraft model into a lateral equation of motion utilized by

the lateral control architecture and a longitudinal equation of motion utilized by the longitudinal control architecture in Gold's flight control system which has separate lateral (roll) and longitudinal (pitch) control architectures.

100. Gold discloses that its control system uses a “**model following algorithm in each control axis**” (yaw, pitch, roll, and vertical). (DJI-1005, 3:25-26; 3:17-18.) Gold further discloses that the flight control system contains separate control modules in the PFCS and AFCS for controlling pitch (longitudinal movement) and roll (lateral movement). However, Gold does not specify the underlying equations used to control lateral and longitudinal movement. A POSITA would have therefore been motivated to search for references that describe these equations in a control system having separate lateral and longitudinal controls and would have been led to Shue. Shue and Gold are in the same field of endeavor as the '082 patent—control systems for aircraft—and are therefore analogous art.

101. A POSITA would have further been motivated to combine Shue's equations and Gold's control system to permit the development of an operational flight control system. Model following control systems were well-known for over 50 years before the earliest possible priority date of the '082 patent. (*See* DJI-1021, 486, 498.) It was equally, if not more well-known, that automatic control of aircraft

and aircraft models utilize the equations of motion for an aircraft. (*see* DJI-1017, 203-414; DJI-1018, 96-130; *see also*, §IIIA.5.) A POSITA would have therefore recognized that Gold's lateral and longitudinal flight controls utilized lateral and longitudinal equations of motion and would have been motivated to combine Shue's disclosures of such equations of motion to achieve Gold's automatic flight control.

102. The combination of Gold's model-following control system having separate lateral and longitudinal control and Shue's teaching of an aircraft model decoupled into lateral equations of motion used by the lateral control architecture and longitudinal equations of motion used by the longitudinal control architecture is simply the combination of prior art elements (Gold's lateral and longitudinal control architectures with Shue's lateral and longitudinal equations of motion). The method of combining Shue's teachings with Gold's flight control system would have been extremely well-known because as I discussed above and further in §IV.B.4, a, d, use of lateral and longitudinal equations of motion in a control system was known for decades prior to the '082 patent.

103. A POSITA would have had a reasonable expectation of success in the combination and the results of the combination would have been predictable because the decoupling of an aircraft model into a lateral equation of motion to

control lateral movement and a longitudinal equation of motion was well-known for almost 50 years before the earliest priority date of the '082 patent.

104. It was also well-known that in practice the aircraft equations of motion are divided into lateral and longitudinal equations of motion when implementing a flight control system. For example, McRuer (1973) depicts an exemplary control system having separate lateral and longitudinal architectures using the lateral and longitudinal equations of motion, respectively. (*See* §III.A.5.) Nelson also described in the book “Flight Stability and Automatic Control” (1998) the concept of separating the aircraft equations of motion into linearized longitudinal equations of motion and lateral equations of motion. (*See* DJI-1018, 104-108.) Philips stresses in “Mechanics of Flight” that for small deviations from equilibrium “no coupling exists between the longitudinal motion and the lateral motion.” (DJI-1019, 720.) This allows each set of equations to be solved independently. (DJI-1019, 720-721.) Because it was well-known to use lateral equations of motion to control lateral motion and longitudinal equations of motion to control longitudinal motion and it was well-known that these equations can be decoupled (*See* §III.A.5), a POSITA would have had a reasonable expectation of success in using lateral equations of motion in Gold’s roll control architecture and longitudinal equations of motion in Gold’s pitch control architecture.

b. Motivation to Combine Gold, Shue, and Gold-Paper

105. A POSITA would have been motivated to combine the teachings of Gold-Paper regarding logic for activating portions of the lateral and longitudinal architectures to perform modes of operation with the combined control system of Gold and Shue. Gold provides details of a type of velocity stabilization mode. (*See, e.g.,* DJI-1005, 3:54-6:57.) Gold further mentions other operating modes for a helicopter, such as automatic turn coordination mode, but fails to provide details regarding the logic used to engage or disengage these operating modes. (*See, e.g.,* DJI-1005, 6:46-48 (stating that switch 557 of Figure 5 “opens in response to the aircraft operating in the **automatic turn coordination** mode”).) A POSITA would have therefore been motivated to search for references describing logic to integrate different operating modes and their engagement/disengagement into a flight control system and would have been led to the Gold-Paper. The Gold-Paper, Shue, and Gold are in the same field of endeavor as the '082 patent—control systems for aircraft—and are therefore analogous art.

106. A POSITA would have further been motivated to combine Gold-Paper's teachings with the combination of Gold and Shue to enhance automatic mode switching in the control system. A POSITA would have understood that it was desirable to limit the need for a pilot to manually engage and disengage

modes. Indeed, one object of Gold is to reduce the pilot's workload. (*See* DJI-1005, 2:20-22, 1:22-25.) Gold-Paper also stresses the goal of reducing pilot workload. (*See, e.g.*, DJI-1009, 419 (“These modes provide increasing levels of vehicle augmentation combined with improved control precision to produce superior flight performance and low pilot workload”), 428 (“Position Hold and Altitude Hold modes, when engaged, alleviated the pilot of virtually all workload in the pitch/roll and collective axes respectively”, 429 (noting that “low speed turn coordination was a major plus in reducing workload for this task”).) A POSITA would have therefore been motivated to integrate automatic mode initialization logic of Gold-Paper into the control system of Gold and Shue to reduce pilot workload and permit the smooth transition between control modes.

107. The combination of the flight control system of Gold and Shue with the teachings of the Gold-Paper is simply the combination of prior art elements (the flight control system of Gold and Shue with the mode initialization logic of the Gold-Paper). A POSITA would have understood how to use known methods to achieve the combination because it was well-known that automatic flight control systems were implemented in software. The Gold-Paper repeatedly references the use of “logic” in its mode switching. (*See, e.g.*, DJI-1009, 424 (discussing the “ALTHLD logic smoothly transitions the aircraft to level flight and then holds

altitude” and the “logic of switching”).) A POSITA would have understood how to integrate the software logic of the Gold-Paper into the automatic flight control system of Gold because software-based control systems were well-known prior to the earliest possible priority date of the ’082 patent. (*See, e.g.*, DJI-1006, 4:58-5:26 (describing a software-based flight control system).)

108. A POSITA would have had a reasonable expectation of success and the results of the combination would have been predictable because Gold and the Gold-Paper both use the same basic architecture for the PFCS and AFCS. Gold describes a model following control system having a PFCS and AFCS each with “control modules for controlling the yaw, pitch, roll and lift axes of the aircraft.” (DJI-1005, 3:17-20.) Gold-Paper also discloses its “PFCS and AFCS use explicit model-following control laws to provide both control and stability augmentation.” (DJI-1009, 419.) The Gold-Paper provides a block diagram of the exemplary longitudinal control which is analogous to Gold’s Figure 4. The Gold-Paper also supports a similar architecture for lateral control. (*See*, DJI-1009, 420 (referencing the lateral axis of the PFCS).)

B. Independent Claim 1

109. The combination of Gold, Shue, and Gold-Paper renders claim 1 obvious. Claim 1 is reproduced below with labels added for ease of discussion.

[1P] An aircraft, comprising:

[1A] a sensor carried by the aircraft, the sensor being adapted to sense a directional movement of the aircraft;

[1B] an actuator carried by the aircraft, the actuator being utilized to control the directional movement of the aircraft; and

[1C] a control system in data communication with the aircraft sensor and operably associated with the actuator, the control system having:

[1C.1] a model adapted to decouple the directional movement of the aircraft into a lateral equation of motion and a longitudinal equation of motion;

[1C.2] a lateral control architecture in data communication with the model, the lateral control architecture being adapted to utilize the lateral equation of motion to control the lateral motion of the aircraft;

[1C.3] a longitudinal control architecture in data communication with the model, the longitudinal control architecture adapted to utilize the longitudinal equation of motion to control the longitudinal motion of the aircraft; and

[1C.4] an initialization command logic in data communication with the lateral control architecture and in data communication with the longitudinal control architecture;

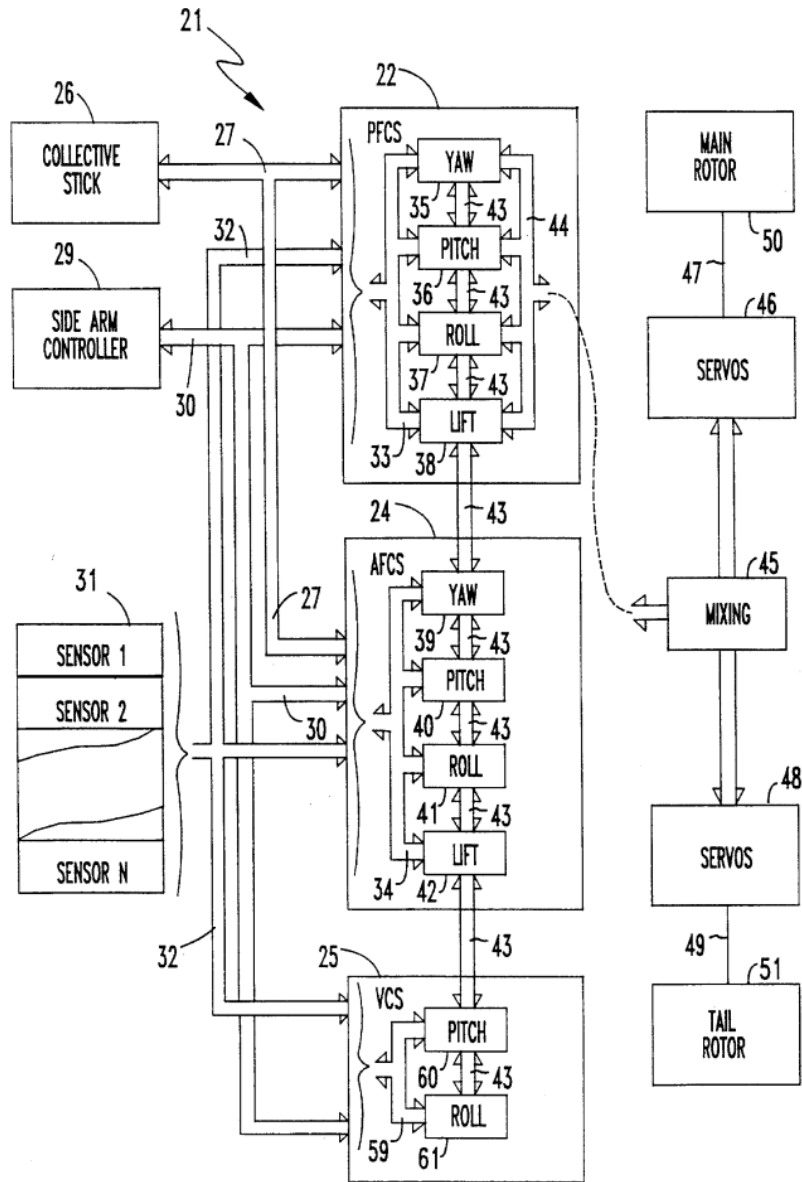
[1D] wherein the initialization command logic selectively activates the lateral control architecture for controlling the lateral motion of the aircraft and selectively activates the longitudinal

control architecture for controlling the longitudinal motion of the aircraft; and

[1E] wherein the control system utilizes the lateral control architecture and the longitudinal control architecture to control speed variations of the aircraft while the aircraft maintains a constant vector heading across a ground surface.

1. Preamble [1P]

110. Gold describes a **flight control system 21**, illustrated in Figure 3 below, including primary **flight** control system (PFCS) 22, automatic **flight** control system (AFCS) 24 and velocity command system (VCS) 25. (DJI-1005, 3:4-7.) Gold describes its system “with respect to a model following flight control system for a rotary winged **aircraft**.” (DJI-1005, 2:65-67.) Therefore, Gold discloses an “*aircraft*.” (See also, DJI-1005, claim 1 (reciting “An **aircraft** flight control system”).)



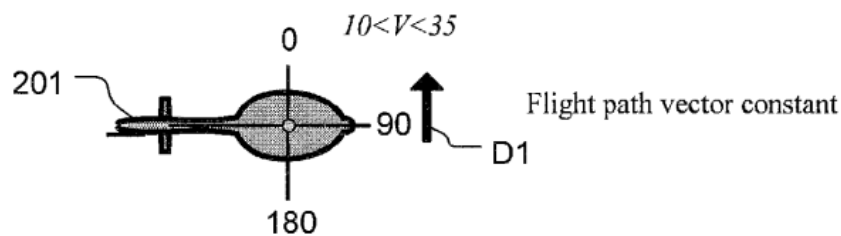
Gold, Figure 3

2. “Sensor” [1A] and “Actuator” [1B].

111. Limitations [1A] and [1B] recite “a sensor carried by the aircraft, the sensor being adapted to sense a directional movement of the aircraft” [1A] and “an actuator being utilized to control the directional movement of the aircraft”

[1B]. Aside from the claim recitation, the '082 patent uses the term “*directional movement*” once in the discussion of Figure 2 (excerpt below). The '082 patent states “[s]tep 2 shows aircraft 201 traveling in forward flight while the fuselage faces 90 degrees relative to the **directional movement**.” (DJI-1001, 3:31-33.) In this citation, the '082 patent equates “directional movement” to the direction in which the aircraft’s center of mass is moving. The '082 patent further associates its directional control architecture to heading control, turn coordination, and yaw control. (See, e.g., DJI-1001, claims 3 and 13.) Accordingly, a POSITA would have understood “*directional movement*” encompasses movement in any direction including lateral, longitudinal, vertical, or yaw.

Step 2: Pedal Turn

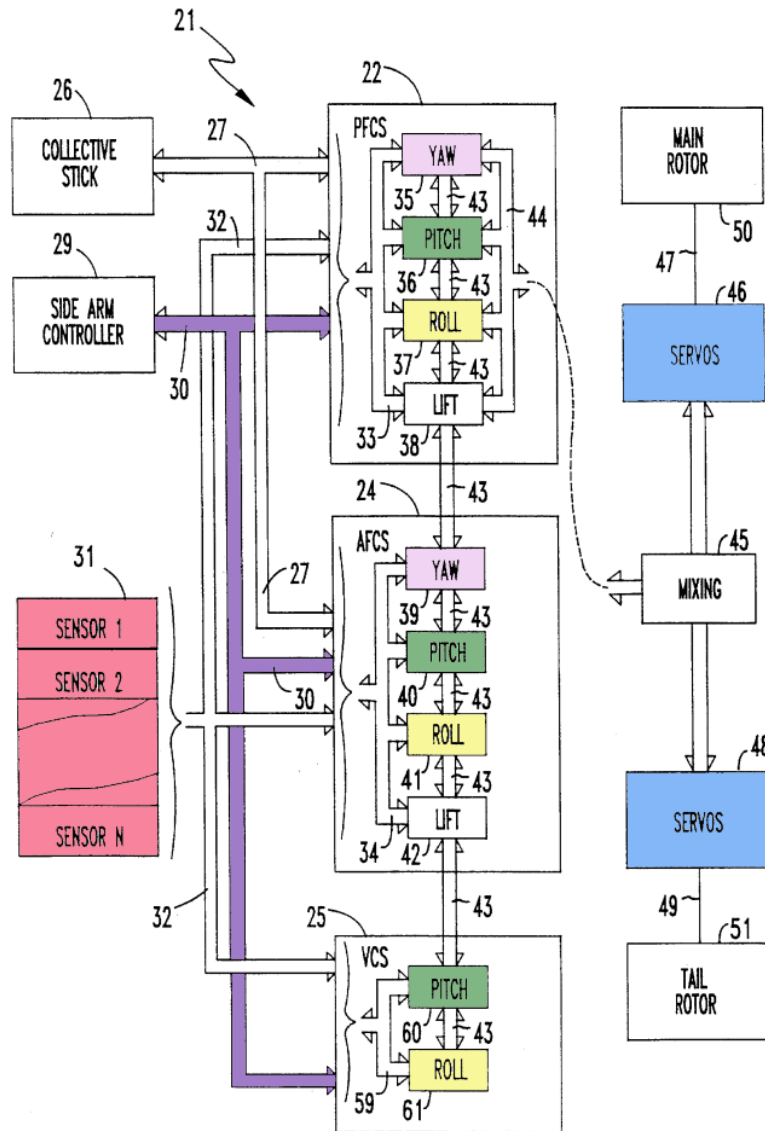


'082 Patent, Excerpt from Figure 2

a. “*Sensor*”

112. The PFCS, AFCS, and VCS of Gold’s flight control system 21 receive “sensed parameter signals from **sensors 31** [shaded red in the annotated version of

Gold Figure 3 below] on lines 32.” (DJI-1005, 3:10-13, 3:39-41.) Therefore, Gold discloses “a sensor carried by the aircraft.”



Gold, Annotated Figure 3

113. The sensed parameter signals provide “the PFCS and AFCS with the aircraft’s angular rate and attitude response to the main rotor and tail rotor

command signals.” (DJI-1005, 3:32-35.) The sensors further provide “information related to velocity, altitude, acceleration, etc.” (DJI-1005, 3:35-36.) For example, the longitudinal groundspeed is provided to the VCS from the sensors on line 150 and the lateral groundspeed is provided from the sensors on line 150a. (DJI-1005, 5:23-26; *see also*, DJI-1005, Figure 5.) By sensing angular rate, velocity (including speed), altitude, and acceleration, Gold discloses the “*sensor being adapted to sense a directional movement [yaw, lateral, longitudinal, vertical movement] of an aircraft*” [1A]. (*See also*, §III.A.2.)

114. Furthermore, U.S. Patent 5,238,203 to Skonieczny, et al (“Skonieczny”), which is incorporated by reference into Gold, provides an exemplary list of sensed aircraft parameters: “actual airspeed (line 60), actual yaw rate (line 64), pitch attitude (line 86), bank angle (PHI) (line 87), roll rate (line 88), lateral acceleration (line 89), heading (line 90), longitudinal ground speed (line 91), and lateral ground speed (line 92).” (DJI-1006, 4:48-53; DJI-1005, 4:38-43 (incorporating Skonieczny by reference).) These sensed parameters confirm that the sensor “*sense[s] a directional movement of an aircraft.*”

b. “Actuator”

115. Gold’s “PFCS and AFCS use a model following algorithm in each control axis to provide rotor command signals on output lines 44 to a rotor mixing

functions 45 which commands displacement of mechanical servos 46 and linkages to control the tip path plane of a main rotor 50” and “tail rotor servos 48 which control the thrust of a tail rotor 51 through linkages 49.” (DJI-1005, 3:25-32.)

Actuators are devices that generally convert electrical signals into pressure, temperature, or mechanical movements. Each control surface of the aircraft has an associated actuator. (See, §III.A.3.) As I discussed in §§III.A.1, 4, the tip path plane of the main rotor is tilted in the direction of the desired motion (e.g., lateral or longitudinal) and the tail rotor controls yaw movement. Accordingly, Gold’s servos and linkages include “*actuators*.” Thus, Gold discloses “*an actuator being utilized to control the directional movement of the aircraft*” [1B].

3. “Control System” [1C]

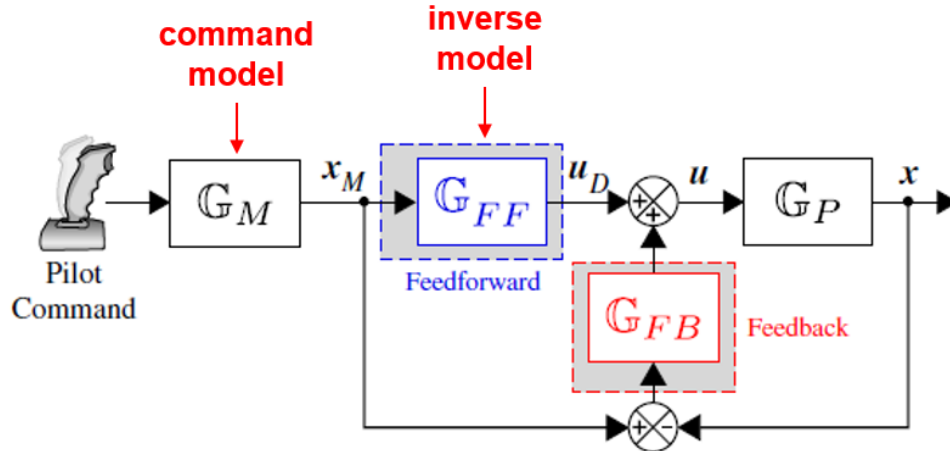
116. Flight control system 21 is a “*control system*.” The PFCS, AFCS, and VCS of Gold’s flight control system 21 each receives “sensed parameter signals from sensors 31 on lines 32.” (DJI-1005, 3:10-13, 3:39-41.) The PFCS and AFCS, in turn, “provide rotor command signals on output lines 44 to a rotor mixing function 45 which commands displacement” of the mechanical servos and linkages of the main and tail rotors (“*actuator[s]*”). (DJI-1005, 3:25-29.) Thus, Gold discloses “*a control system in data communication with the aircraft sensor and operably associated with the actuator*” [1C].

4. Model, Lateral and Longitudinal Control Architecture Limitations [1C.1]-[1C.3]

117. Limitations [1C.1]-[1C.3] interweave the concepts of a “*model*”, “*equations of motions*”, “*lateral control architecture*”, and “*longitudinal control architecture*.” I address each concept separately in this section. Because Gold primarily describes the functional interconnection of modules within its flight control system with respect to the pitch axis (longitudinal) control modules, I address the longitudinal control architecture prior to the lateral control architecture.

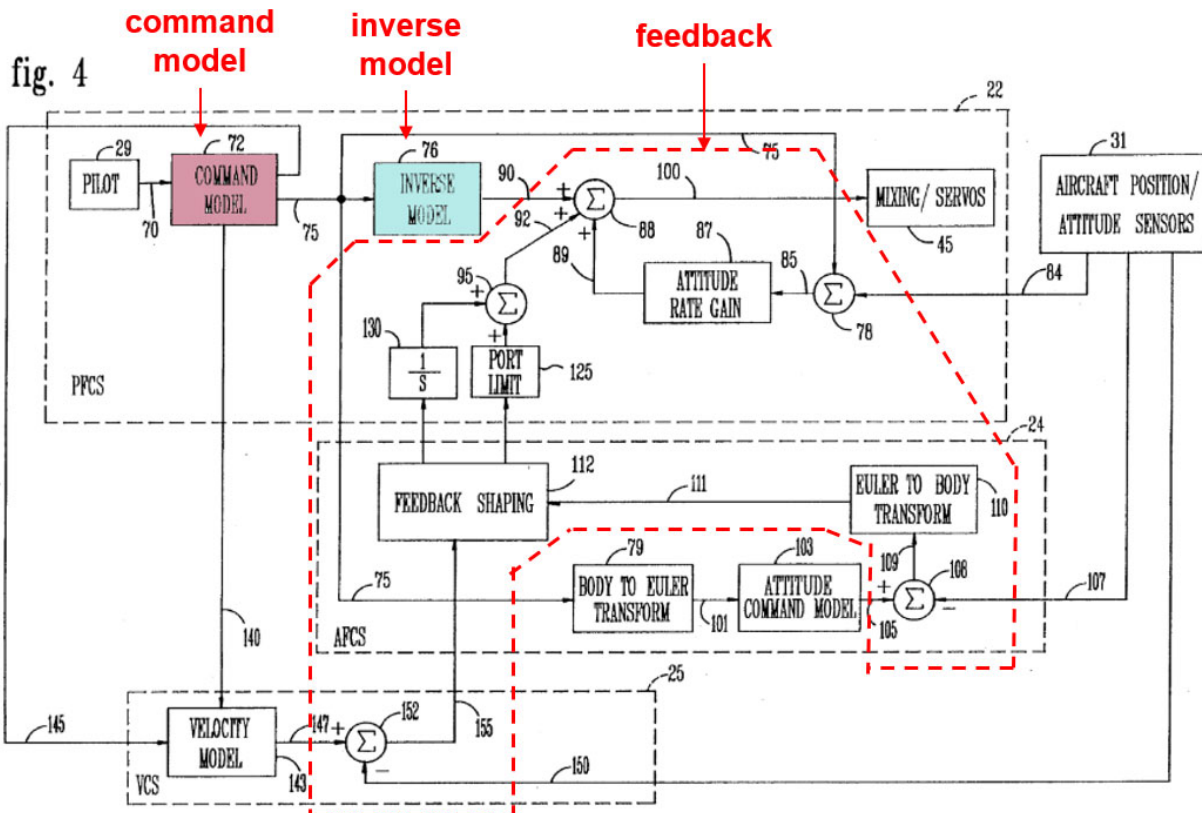
a. “*Model*”

118. Claim 1 recites that the control system includes “*a model*” [1C.1] that is in data communication with both the lateral and longitudinal control architectures. As I discussed in §III.A.5, “model-following” control systems include a model in the control system and were known for 50 years before the earliest possible priority date of the ’082 patent. The following figure from Adams/Singhose (DJI-1022) describes the general structure of an explicit model-following control system such as disclosed 50 years before the earliest possible priority date of the ’082 patent by Tyler (DJI-1021). Adams/Singhose represents this well-known structure in Figure 6, which has been reproduced below in annotated form. Gold discloses such an explicit model-following control system.



Adams/Singhose (DJI-1022), Annotated Figure 6

119. Gold’s control system uses a “**model following algorithm** in each control axis” (yaw, pitch, roll, and vertical). (DJI-1005, 3:25-26; 3:17-18.) Figure 4, reproduced below, illustrates “the functional interconnection of the VCS 25 with the PFCS 22 and the AFCS 24” and is described primarily with respect to the pitch axis (longitudinal) control modules 36, 40, 60. (DJI-1005, 3:54-56.) However, Gold’s Figure 4 is “equally applicable to flight control roll attitude reference and VCS roll axis velocity error signals.” (DJI-1005, 3:58-61.) I have annotated Figure 4 to highlight the command model, inverse model, and feedback portions of the control module.



Gold, Annotated Figure 4

120. Command model 72 (shaded red) receives commands from the pilot's controller and shapes these pilot commands "to yield a desired rate and/or attitude response." (DJI-1005, 4:6-7.) Inverse model 76 (shaded blue) "provides a control command signal on a line 90 which represents the approximate rotor command necessary to achieve the desired pitch axis rate of change of the aircraft for each pilot commanded maneuver." (DJI-1005, 4:10-15.) The inverse model cancels undesired dynamics using model inversion techniques and generates inputs that command the aircraft to approximately follow the command model response. (See

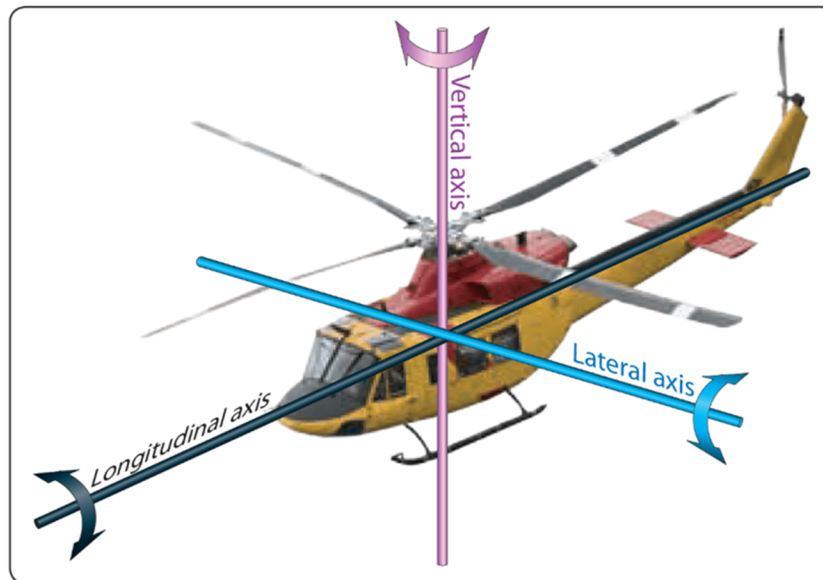
§III.A.5.) The desired control command signal(s) are provided by the inverse model(s) to the feedback portion of the control module, as illustrated in annotated Figure 4 above.

121. Pitch/roll control in Gold uses a command model and inverse model for the PFCS, AFCS, and VCS pitch/roll control modules. The command model and inverse model for pitch control are both a “*model*” for the pitch axis and the command model and inverse model for roll control are both a “*model*” for the roll axis. Because Gold’s control system uses a “**model following algorithm** in each control axis” (yaw, pitch, roll, and lift), the yaw and lift controls also include a command model and an inverse model. (See DJI-1005, 3:25-26; 3:17-18.) The command and inverse models for the pitch axis, the command and inverse models for the roll axis, the command and inverse models for the yaw axis, and the command and inverse models for the lift axis are, therefore, collectively a “*model*” for the aircraft. Thus, Gold discloses that the “*control system*” has a “*model*.”

122. I address the remaining portions of “*model*” limitation [1C.1] associated with the “*lateral equation of motion*” and “*longitudinal equation of motion*” in §IV.B.4.d addressing “*equations of motion*.”

b. “Longitudinal Control Architecture”

123. Gold’s “control system” includes “a longitudinal control architecture” that “control[s] longitudinal motion of the aircraft” [1C.3]. As I discussed in §III.A, a coordinate system for an aircraft consists of three perpendicular axes—a longitudinal axis, a lateral axis, and a vertical axis. Such a coordinate system is shown in the figure below.



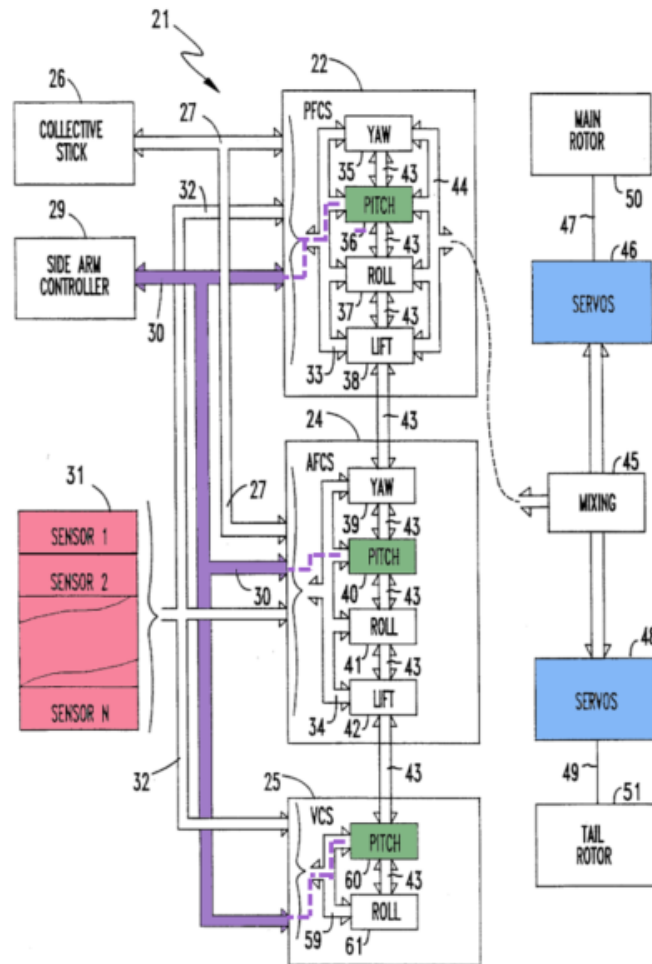
Helicopter Aerodynamics - Aircraft Theory of Flight (Part 5)

124. Rotation about the lateral axis is referred to as pitch. Changes in pitch angle (attitude) induces longitudinal motion, as I discussed in §§III.A.1, 4 Specifically, when the main rotor is pitched forward, a portion of its thrust is in the longitudinal direction, thereby inducing longitudinal motion. Thus, controlling pitch controls the longitudinal motion of the aircraft. This correlation of pitch and

longitudinal control is similarly taught by the '082 patent: “architecture 601 preferably comprises of a longitudinal control law for forward speed, represented as block 605 ‘Long_SPD’; a **longitudinal control law for pitch angle**, represented as block 607 ‘Long_ATT’; and, a **longitudinal control law for pitch rate**, represented as block 609 ‘Long_RATE.’” (DJI-1001, 4:64-5:2.) Therefore, controlling pitch controls “*the longitudinal motion of the aircraft.*”

125. The PFCS and AFCS of Gold’s flight control system 21 each contains a control module for controlling pitch of the aircraft. (DJI-1005, 3:17-18.) These pitch control modules 36 and 40 are highlighted in green in the annotated version of Gold’s Figure 3 provided below. VCS 25 also contains a control module for providing pitch axis velocity error signals to the AFCS and PFCS. (DJI-1005, 3:45-46.) Therefore, pitch control module 60 in the VCS is a third pitch control module disclosed by Gold. The PFCS and AFCS each receive the output command signals of sidearm controller 29 on lines 30 and sensed parameter signals from sensors 31 on lines 32. (DJI-1005, 3:10-13.) The VCS “receives the force output command signals of sidearm controller 29 on lines 30 and sensed parameter signals from sensors 31 on lines 32.” (DJI-1005, 3:40-42.) The pitch control architecture of the PFCS and AFCS “provide rotor command signals to output lines 44 to a rotor mixing function 45 which commands displacement of mechanical servos 46

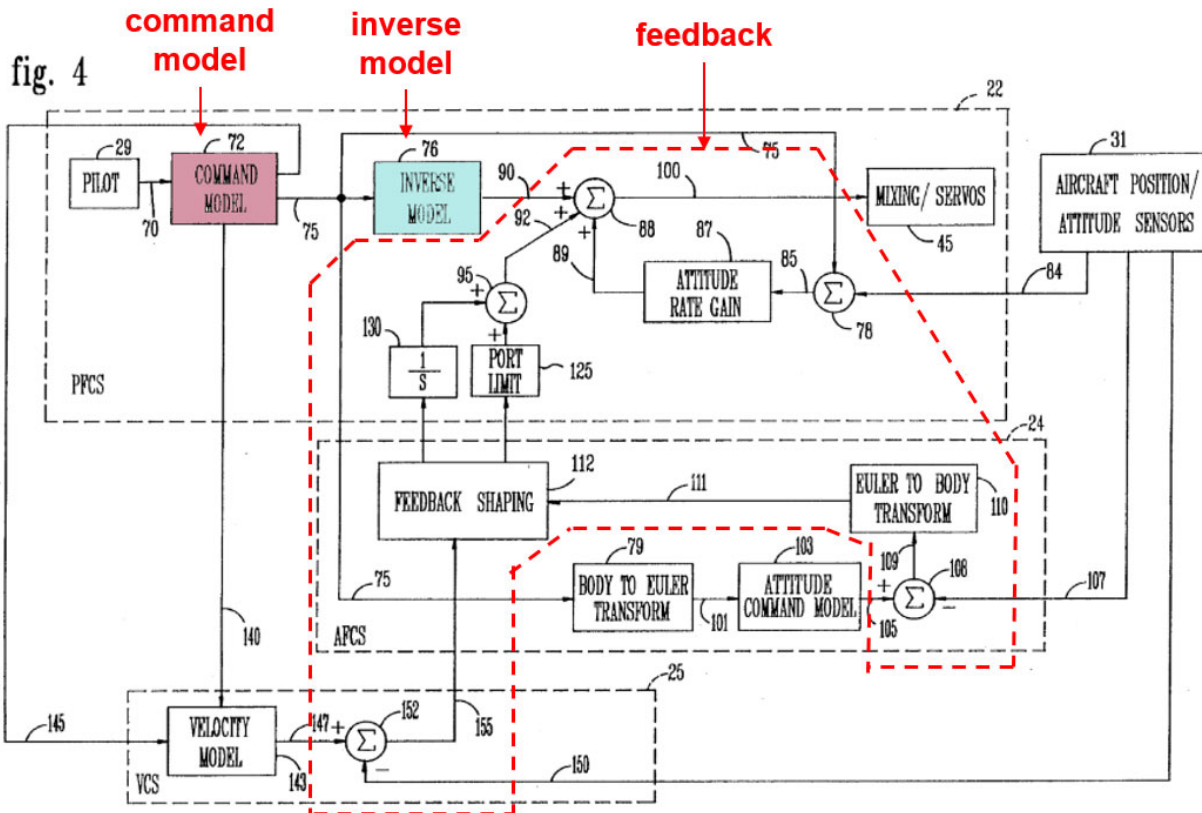
and linkages 47 to control the tip path plane of a main rotor 50” as shown on the right side of Figure 3 below. (DJI-1005, 2:25-29.)



Gold, Annotated Figure 3

126. As I discussed in the previous section, Gold’s control system uses a “**model following algorithm** in each control axis.” (DJI-1005, 3:25-26; 3:17-18.) As illustrated in annotated Figure 4 (reproduced again below for convenience),

pitch control includes pitch axis command model 72, inverse model 76, and a feedback portion.



Gold, Annotated Figure 4

127. The pitch control module 36 of the PFCS, the pitch control module 40 of the AFCS, and the pitch control module 60 of the VCS are collectively part of the “*longitudinal control architecture*” [1C.3] of the flight control system 21. Should an argument be made that the longitudinal command model is separate from the control architecture, a POSITA would have understood that the feedback portion of Gold’s pitch axis control is also a “*longitudinal control architecture*”

because it is responsible for generating the rotor commands to drive the servos/linkages (“*actuator[s]*”) of the aircraft.

128. Because Gold’s inverse model generates “a control command signal on a line 90 which represents the approximate rotor command necessary to achieve the desired” response for the control axis (DJI-1005, 4:10-15) and the command model provides shaped commands (DJI-1005, 4:6-7), Gold discloses “*a longitudinal control architecture in data communication with the model*” [1C.3].

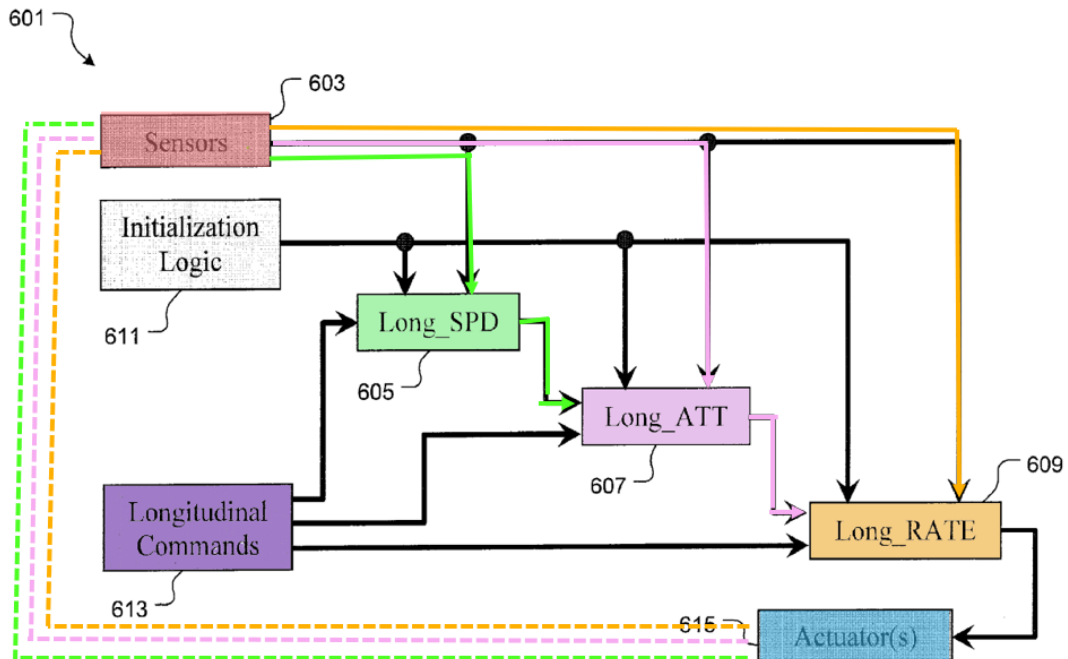
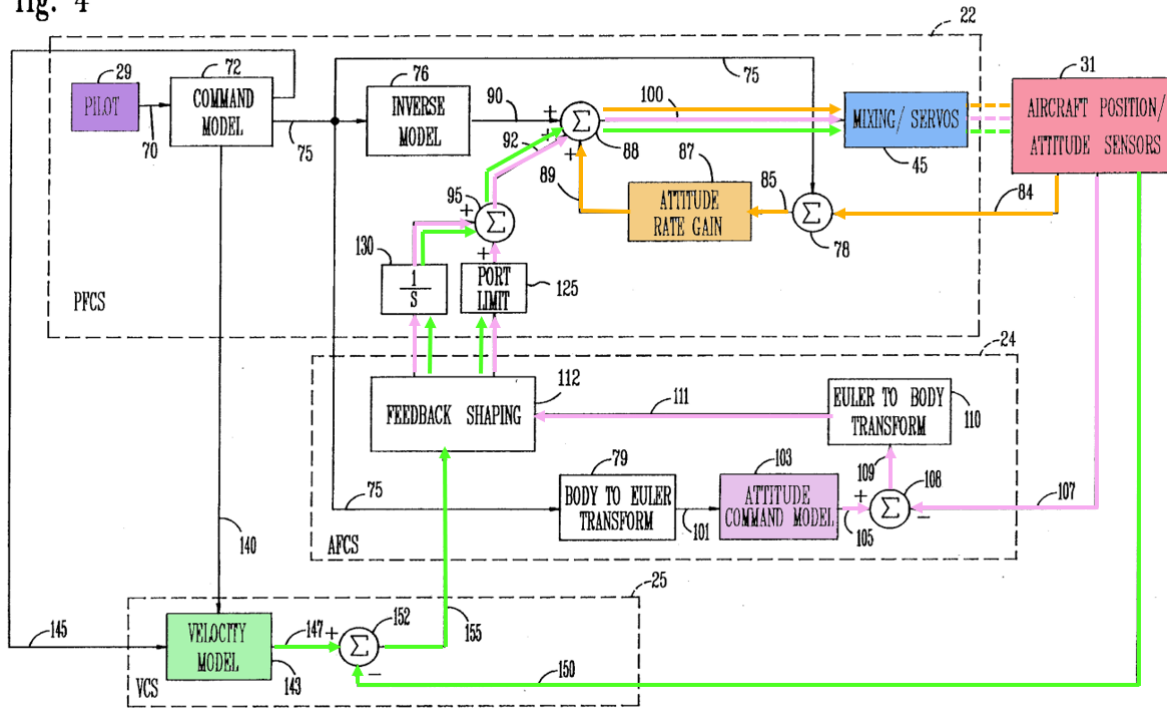
129. I note that the specification appears to include sensors and commands in the “*longitudinal control architecture.*” (See, DJI-1001, 4:43-44 (“architecture 601 includes one or more aircraft sensors”; 5:9-11 (“Architecture 601 further includes a longitudinal command 613 generated in the control laws by referencing the pilot’s cockpit control input in each axis.”).) The sensors detecting longitudinal movement, the longitudinal commands generated by the sidearm controller (shaded purple in annotated Figure 3) and the servos 46 and linkages 47 (actuators) associated with controlling pitch would also be considered by a POSITA to be part of the “*longitudinal control architecture.*” Therefore, Gold also discloses this limitation if these components are considered to be part of the “*longitudinal control architecture.*”

130. Gold’s longitudinal control architecture determines the attitude (pitch angle) of the aircraft, attitude (pitch angle) rate, and aircraft longitudinal velocity including longitudinal forward speed. It accomplishes these control functions by providing a command signal to the mixing function which, in turn, commands displacement of mechanical servos and linkages which “control the tip path plane of a main rotor 50.” (DJI-1005, 3:25-29.) As I discussed above, changing the pitch of the main rotor induces longitudinal motion and, therefore, Gold’s pitch control architecture “*control[s] longitudinal motion of the aircraft.*” I address the portion of limitation [1C.3] directed to “*utiliz[ation of] the longitudinal equation of motion*” in §IV.B.4.d addressing “*equations of motion.*”

131. Gold’s longitudinal control architecture is analogous to the longitudinal control architecture of the ’082 patent. The analogous nature is illustrated below in Gold’s annotated Figure 4 (top figure below) and Figure 6 of the ’082 patent (bottom figure below). (See DJI-1005, 3:54-6:57; DJI-1001, 4:43-63.) As shown below, like the ’082 patent, Gold discloses a longitudinal control law for forward speed, referred to in dependent claims 8 and 18 of the ’082 claims as a longitudinal speed loop (indicated by the green lines), a longitudinal control law for pitch angle, referred to in dependent claims 8 and 18 of the ’082 claims as an attitude (pitch angle) loop (indicated by the pink lines), and a longitudinal

control law for pitch rate, referred to in dependent claims 8 and 18 of the '082 claims as a pitch rate loop (indicated by the orange lines). I describe each of these loops in further detail below in my analysis of dependent claims 8 and 18.

fig. 4



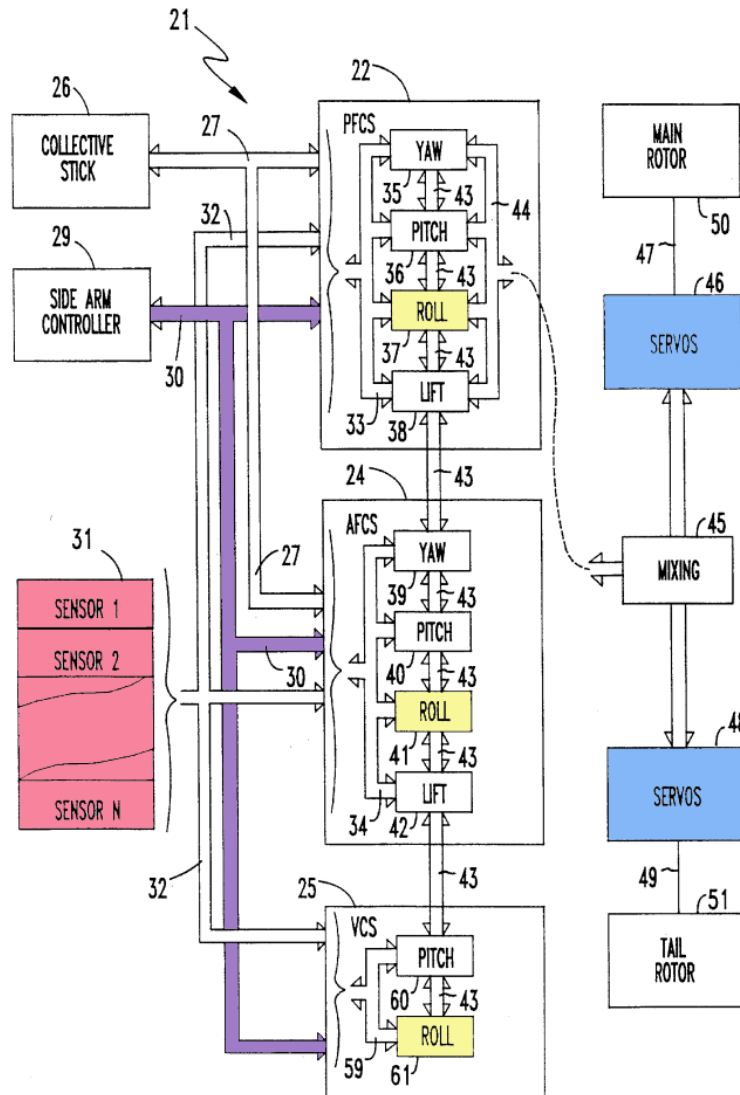
Gold, Annotated Figure 4 (top); '082 Patent, Annotated Figure 6 (bottom)

c. “Lateral Control Architecture”

132. Gold’s “control system” also includes “a lateral control architecture” that “control[s] the lateral motion of the aircraft” [1C.2]. As I discussed in §§III.A.1, 4, rotation about the longitudinal axis of the aircraft is referred to as roll. Specifically, when the main rotor is “rolled” (or tilted) sideways, a portion of its thrust is in the lateral direction, thereby inducing lateral motion. Therefore, controlling roll controls the lateral motion of the aircraft. Like the correlation between pitch and longitudinal control, the correlation between roll and lateral control is taught by the ’082 patent: “architecture 701 comprises one or more lateral control laws operably associated with sensors 603, logic 611, lateral commands 702, and actuators 615. The lateral control laws include: a **lateral control of roll rate**, represented as block 703 ‘Lat_RATE’; a **lateral control of the roll attitude**, represented as block 705 ‘Lat_ATT’ ...” (DJI-1001, 5:41-47.) Therefore, controlling roll controls “the lateral motion of the aircraft.”

133. The PFCS and AFCS of Gold’s flight control system 21 each contains a control module (shaded yellow in annotated Figure 3 below) for controlling roll of the aircraft. (DJI-1005, 3:17-18.) The VCS also contains a control module for providing roll axis velocity error signals to the AFCS and PFCS. (DJI-1005, 3:45-

46.) Therefore, Gold's flight control system includes 3 roll control modules, as shown below.



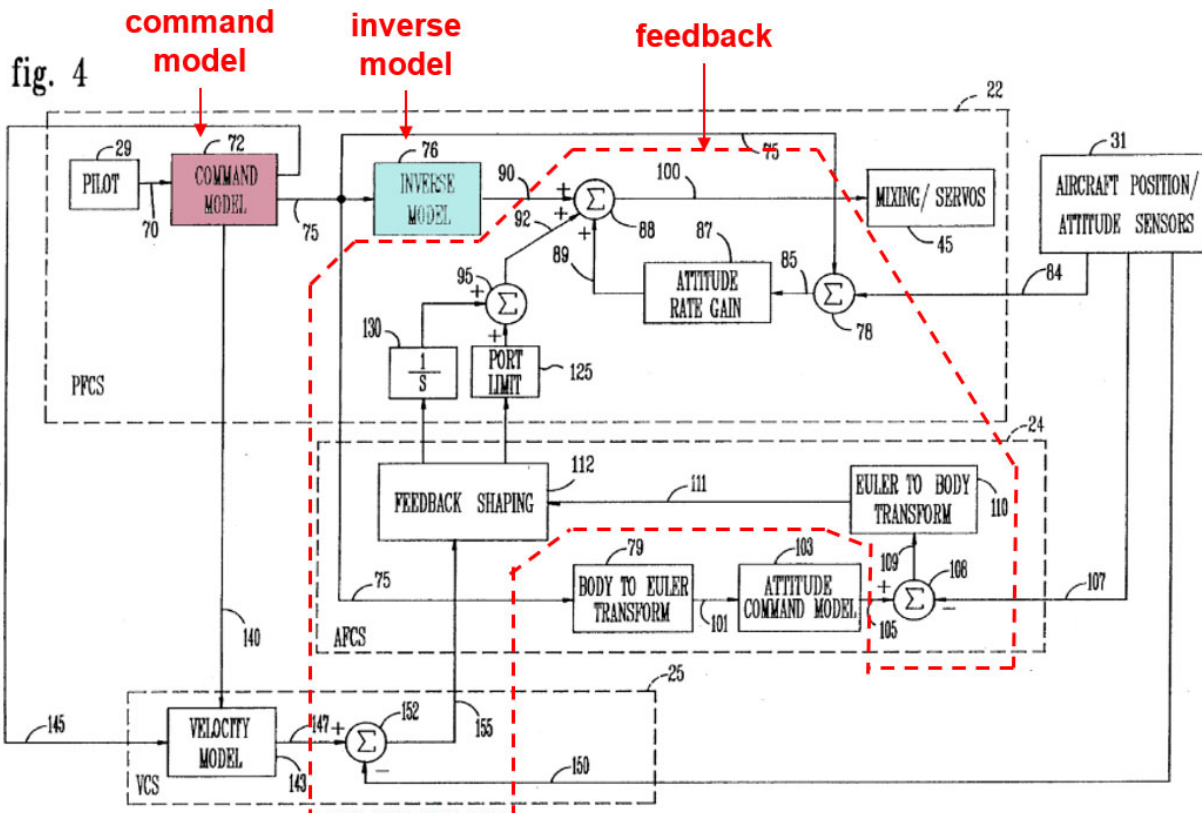
Gold, Annotated Figure 3

134. The PFCS and AFCS “each receive the force output command signals of a four-axis sidearm controller 29 on lines 30 and sensed parameter signals from sensors 31 on lines 32.” (DJI-1005, 3:10-13.) The VCS “receives the force output

command signals of sidearm controller 29 on lines 30 and sensed parameter signals from sensors 31 on lines 32.” (DJI-1005, 3:40-42.) The roll control architecture of the PFCS and AFCS “provide rotor command signals to output lines 44 to a rotor mixing function 45 which commands displacement of mechanical servos 46 and linkages 47 to control the tip path plane of a main rotor 50” as shown on the right side of Figure 3 above. (DJI-1005, 2:25-29.)

135. As I discussed previously, Gold’s control system uses a “**model following algorithm** in each control axis.” (DJI-1005, 3:25-26; 3:17-18.) As illustrated in annotated Figure 4³ (reproduced again below for convenience), roll control includes roll axis command model 72, inverse model 76, and a feedback portion.

³ Gold describes Figure 4 with respect to pitch axis modules 36, 40, 60 but, as explained by Gold, “the functional interconnection of FIG. 4 is equally applicable to flight control roll attitude reference and VCS roll axis velocity error signals.” (DJI-1005, 3:54-61.) Therefore, Figure 4 applies to Gold’s roll control architecture.



Gold, Annotated Figure 4

136. The roll control module 37 of the PFCS, the roll control module 41 of the AFCS, and the roll control module 61 of the VCS are collectively part of the “*lateral control architecture*” [1C.2] of flight control system 21. Should an argument be made that the lateral command model is separate from the control architecture, a POSITA would have understood that the feedback portion of Gold’s pitch axis control is also a “*lateral control architecture*” because it is responsible for generating the rotor commands to drive the servos/linkages (“*actuator[s]*”) of the aircraft.

137. Because Gold's inverse model generates "a control command signal on a line 90 which represents the approximate rotor command necessary to achieve the desired" response for the control axis (DJI-1005, 4:10-15) and the command model provides shaped commands (DJI-1005, 4:6-7), Gold discloses "*a lateral control architecture in data communication with the model*" [1C.2].

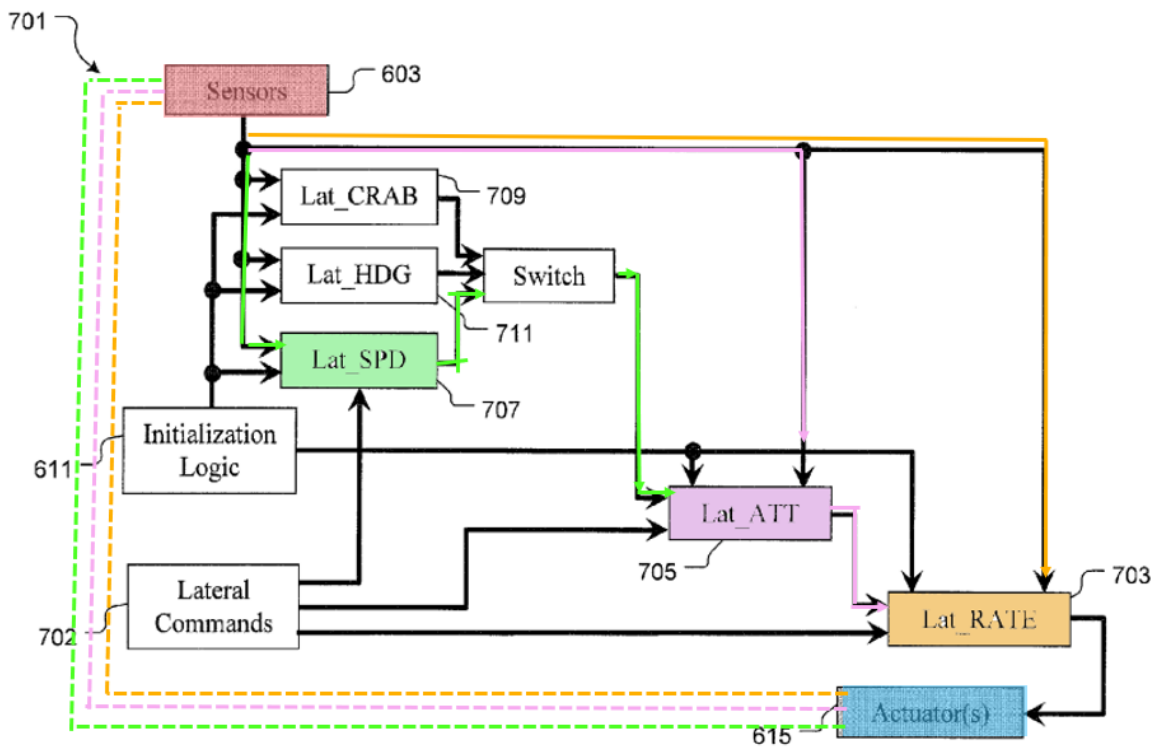
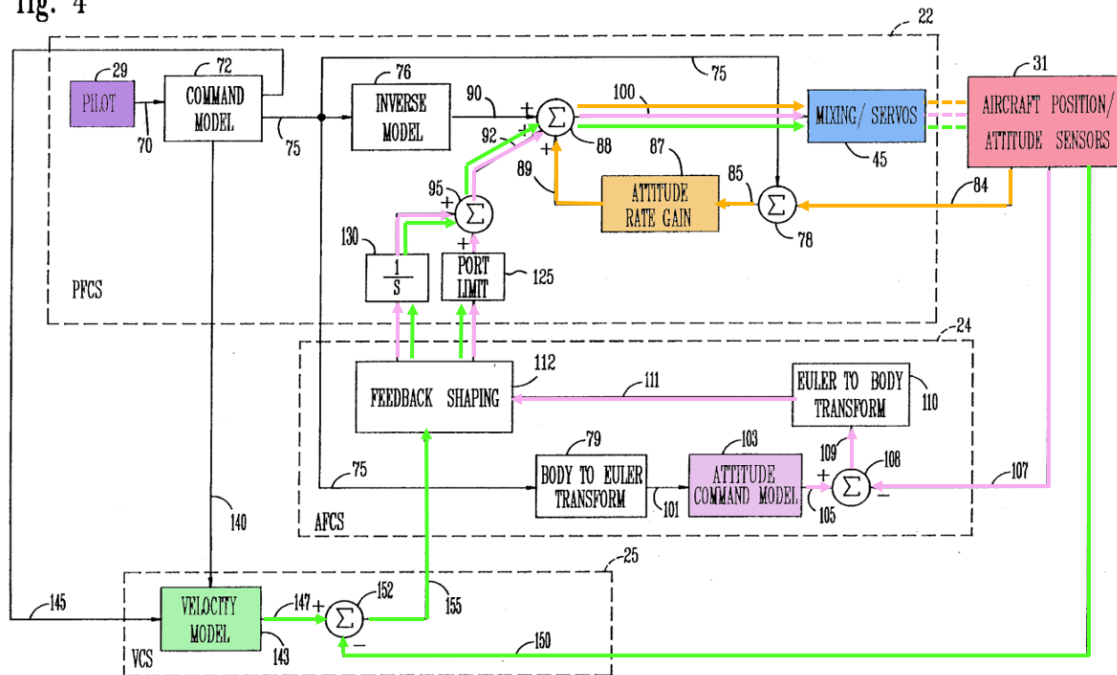
138. As I discussed in the prior section, the specification appears to include sensors and commands in the "*longitudinal control architecture*." I note that the discussion of the "*lateral control architecture*" does not include similar language. (See, '082 patent, 5:41-50.) Regardless, sensors detecting lateral movement, the lateral commands generated by the sidearm controller (shaded purple in annotated Figure 3), and the servos 46 and linkages 47 (actuators) associated with controlling roll would also be considered by a POSITA to be part of the "*lateral control architecture*." Therefore, Gold discloses this limitation if these components are considered to be part of the "*lateral control architecture*." [1C.2].

139. Gold's lateral control architecture determines the attitude (roll angle), roll attitude rate (how fast aircraft is rolling), and aircraft lateral velocity including lateral ground speed. It performs these control functions by providing a command signal to the mixing function which commands displacement of mechanical servos and linkages which "control the tip path plan of a main rotor 50." (DJI-1005, 3:25-

29.) As I discussed above, changing the roll angle of the main rotor induces lateral motion and, therefore, Gold's roll control architecture "*control[s] lateral motion of the aircraft.*" I address the portion of limitation [1C.2] directed to "*utiliz[ation of] the lateral equation of motion*" in §IV.B.4.d addressing "*equations of motion.*"

140. Gold's lateral control architecture is analogous to the lateral control architecture of the '082 patent, as illustrated below in Gold's annotated Figure 4 (top figure below) and Figure 7 of the '082 patent (bottom figure below). As shown, like the '082 patent, Gold discloses a lateral control of sideward groundspeed, referred to as the lateral speed loop in dependent claims 5 and 15 of the '082 patent claims (indicated by the green lines), a lateral control of the roll attitude, referred to as a lateral roll attitude control loop in dependent claims 5 and 15 of the '082 patent claims (indicated by the pink lines), and a lateral control of roll rate, referred to as a lateral roll rate control loop in dependent claims 5 and 15 of the '082 patent claims (indicated by the orange lines). I describe each of these loops in further detail in my analysis of dependent claims 5 and 15.

fig. 4



Gold, Annotated Figure 4 (top); '082 Patent, Annotated Figure 7 (bottom)

d. “Equations of Motion”

141. Limitation [1C.1] recites that the “*model*” is “*adapted to decouple the directional movement of the aircraft into a lateral equation of motion and a longitudinal equation of motion.*” The detailed description of the ’082 patent has a limited discussion of the concept of a “model” and “decoupling”, which I reproduce below in its entirety:

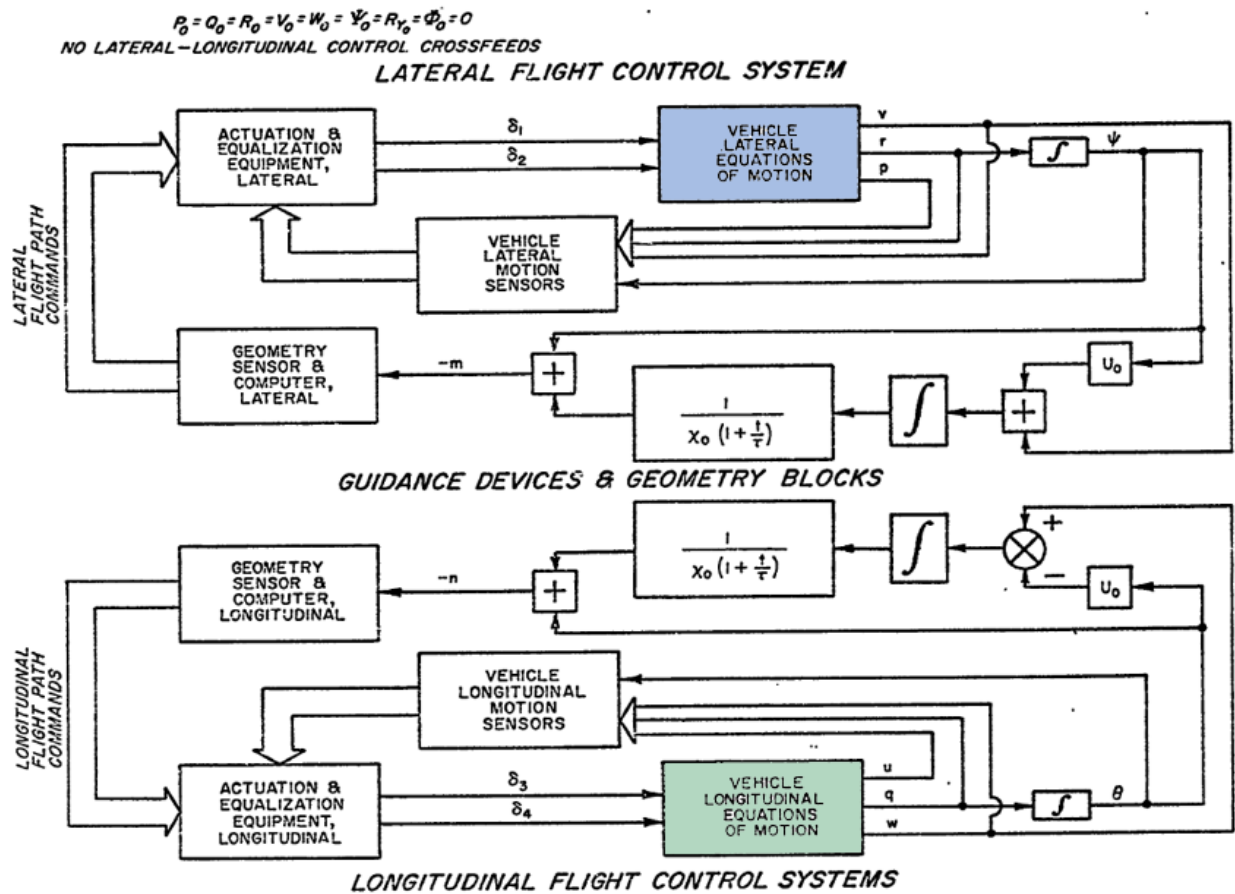
An aircraft model can be obtained from aerodynamics data and a group of linear models can be developed based on its airspeed from aircraft sensors 603. These linear models include both lateral and longitudinal equations of motion. Since the aircraft model matrices are large and contain coupling terms of lateral and longitudinal motions within the matrices, it is difficult to determine the best performance control gains for all at the same time. In order to overcome these issues, the linear model of aircraft performance is decoupled first. After the aircraft model is decoupled to lateral and longitudinal equations of motion, the effect of coupling terms between lateral and longitudinal motions can be reduced to a minimum, thus stabilizing the system.

(DJI-1001, 4:51-63.) The above disclosure (and the ’082 patent in general) does not describes what it means to decouple the aircraft model “to lateral and longitudinal equations of motions.” In fact, the ’082 patent indicates that its “decoupling” does not preclude the existence of some coupling between the

separated longitudinal and lateral equations. Specifically, the '082 patent teaches that with its decoupling “the effect of coupling terms between lateral and longitudinal motions can be **reduced to a minimum**”, indicating that some degree of coupling still exists. (DJI-1001, 4:60-63.)

142. Gold does not explicitly mention that its flight control system utilizes the aircraft “*equations of motion*.” However, a POSITA would have understood that Gold’s flight control system uses the aircraft “*equations of motion*” to cause the movement of the aircraft in any of its six directions of motion because it uses both command models and inverse models associated with the dynamics of the aircraft. Such models incorporate “*equations of motion*.” (See, e.g., §III.A.5.) The command model alters (shapes) the command to better achieve the desired response. A POSITA would have understood that the command model uses equations that describe how the aircraft responds to commands. The inverse model are equations of motion used in reverse. That is, instead of putting inputs into the equations and calculating the predicted aircraft response, the equations are used by putting the desired responses into the equations and calculating what inputs would be needed to produce the desired response. Thus, the inverse model uses the “*equations of motion*.” A POSITA would have understood that a lateral equation of motion is used in the control of lateral motion and that a longitudinal equation of

motion is used in the control of longitudinal motion. As I detailed in §III.A.5, it was also known for almost 50 years that the equations of motions for an aircraft are linearized using small-perturbation theory, allowing for the separation into longitudinal equations of motion and lateral equations of motion. (See DJI-1018, 104-108; DJI-1019, 720; DJI-1017, 297-298, 353-354.) These well understood concepts are illustrated in the following Figure from the **1973 version** of “Aircraft Dynamics and Automatic Control” by McRuer. The exemplary control system in this figure includes a lateral control component (shaded blue) utilizing lateral equations of motion and a longitudinal control component (shaded green) utilizing longitudinal equations of motion. (DJI-1017, 14, 16.)



McRuer (1973), Figure 1-4

143. Gold similarly separates its control system architecture into lateral and longitudinal components, as discussed in §§IV.B.4, b and c. Based on common knowledge in the art, as reflected in McRuer's diagram above and the references discussed in §III.A.5.b, describing separation of the linearized equations of motion into linear and longitudinal components, a POSITA would have understood that Gold's "model" is "adapted to decouple [separate] the directional movement of the aircraft into a lateral equation of motion and a longitudinal equation of motion."

A POSITA would have also understood that Gold’s “*lateral control architecture*” is “*adapted to utilize the lateral equation of motion to control the lateral motion of the aircraft*” [1C.2] and that its “*longitudinal control architecture*” is “*adapted to utilize the longitudinal equation of motion to control the longitudinal motion of the aircraft*” [1C.2].

144. Regardless, Shue explicitly discloses using decoupled lateral and longitudinal equations of motion in lateral and longitudinal control architectures, using similar language to the ’082 patent. Shue explains that “a linear model of aircraft can be obtained from aerodynamics data, and a group of linear models can be developed based on its airspeed.” (DJI-1008, ¶41.) The linear models can be represented by the following equation (1):

$$\begin{aligned}\dot{X} &= A_k X + B_k U \\ Y &= C_k X \text{ where } k=0, 1, 2 \dots, \text{ or } j\end{aligned}$$

where X is the state variables, U is the control vector, and Y is performance output vector. (DJI-1008, ¶41.) “A₀, A₁, A₂ are the state matrices with k=0 for hover, k=1 for 10 knots and k=2 for 20 knots, respectively.” (DJI-1008, ¶41.) “B₀, B₁, B₂ are the control matrices, and C₀, C₁, C₂ are the performance output matrices.” (DJI-1008, ¶41.)

145. Because these matrices are “large and contain coupling terms of lateral and longitudinal motions,” “it is difficult to determine the best performance LQR control gains for all at the same time.” (DJI-1008, ¶41.) To overcome these difficulties, the full model is decoupled into “lateral and longitudinal equations of motion.” (DJI-1008, ¶41.) The lateral equation of motion is given by Shue equation (2) below:

$$\begin{aligned}\dot{X}^{\text{lat}} &= A_k^{\text{lat}} X^{\text{lat}} + B_k^{\text{lat}} U^{\text{lat}} \\ Y^{\text{lat}} &= C_k^{\text{lat}} X^{\text{lat}} \text{ where } k=0, 1, 2 \dots, \text{ or } j\end{aligned}$$

The longitudinal equation of motion is given by Shue equation (3) below:

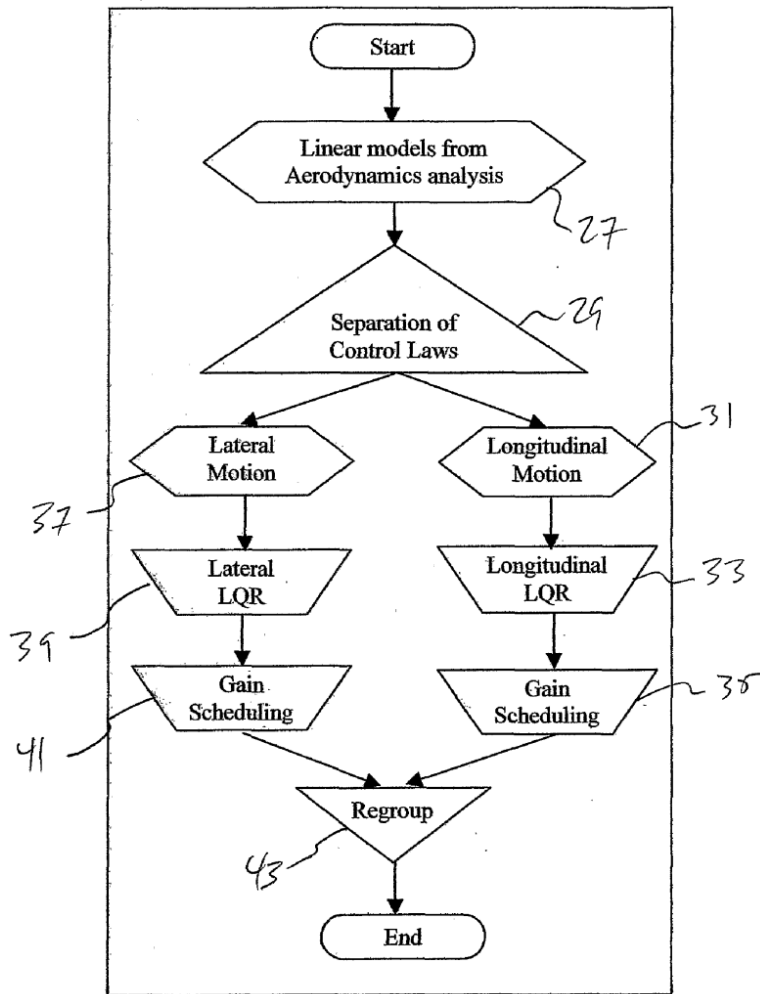
$$\begin{aligned}\dot{X}^{\text{long}} &= A_k^{\text{long}} X^{\text{long}} + B_k^{\text{long}} U^{\text{long}} \\ Y^{\text{long}} &= C_k^{\text{long}} X^{\text{long}} \text{ where } k=0, 1, 2 \dots, \text{ or } j\end{aligned}$$

where X^{lat} is $(v, \phi, p, r)^T$, X^{long} is $(u, w, \theta, q)^T$, U^{lat} is $(\delta_{\text{ped}}, \delta_{\text{lat}})^T$, and U^{long} is $(\delta_{\text{long}}, \delta_{\text{coll}})^T$. (DJI-1008, ¶43.)

146. That is, Shue decouples its model into a lateral equation of motion and a longitudinal equation of motion.

147. Shue illustrates the separation (decoupling) of its aircraft model into the lateral and longitudinal equations of motion in Figure 5 below. In this figure, block 27 “represents the linear models” obtained from aerodynamic data and developed based on airspeed. (DJI-1008, ¶41.) As discussed above, these models

are decoupled into lateral equations of motion (lateral control laws) and longitudinal equations of motion (longitudinal control laws) as illustrated in block 29 and blocks 31 and 37. The lateral equations of motion are represented by equation (2) above and the longitudinal equations of motions by equation (3). (DJI-1008, ¶42.) The lateral control architecture (lateral LQR) uses the lateral equations of motion to minimize a lateral cost function and the longitudinal control architecture (longitudinal LQR) uses the longitudinal equations of motion to minimize a longitudinal cost function to drive condition errors to zero. (DJI-1008, ¶43.)



Shue, Figure 5

148. As discussed in §IV.A.4, the combination of Gold, Shue, and Gold-Paper uses Shue's explicit teachings that the aircraft model is decoupled into lateral and longitudinal equations of motion in the flight control system of Gold having separate lateral and longitudinal control architectures. Therefore, the combination of Gold, Shue, and Gold-Paper discloses "*a model adapted to decouple the directional movement of the aircraft into a lateral equation of motion*

and a longitudinal equation of motion” [1C.1]. The combination of Gold, Shue, and Gold-Paper further discloses the “*lateral control architecture adapted to utilize the lateral equation of motion to control the lateral motion of the aircraft*” [1C.2] and the “*longitudinal control architecture adapted to utilize the longitudinal equation of motion to control the longitudinal motion of the aircraft*” [1C.3].

5. “Initialization Command Logic” [1C.4], [1D]

149. The combination of Gold, Shue, and Gold-Paper discloses “*initialization command logic*” [1C.4]. The Gold-Paper describes multiple examples of “*command logic*” that initialize modes of operation in the lateral (roll) and longitudinal (pitch) architectures.

150. As a first example, the Gold-Paper teaches that “[a]utomatic turn coordination is enabled above 60kts.” (DJI-1009, 421.) The “turn coordination function provides longitudinal, lateral and directional body axis rate commands which minimize lateral acceleration in a turn.” (DJI-1009, 421.) That is, the logic receives data from the sensors and when speed of the aircraft is above 60kts, the logic selectively activates the necessary portions of the lateral, longitudinal, and directional control architectures to perform turn coordination. For this reason alone, the Gold-Paper discloses “*initialization command logic in data communication with the lateral control architecture and in data communication*

with the longitudinal control architecture” [1C.4] where “the initialization command logic selectively activates the lateral control architecture for controlling the lateral motion of the aircraft and selectively activates the longitudinal control architecture for controlling the longitudinal motion of the aircraft” [1D].

151. The Gold-Paper also discloses the automatic activation of various other operating modes by the “*initialization command logic*” in the control system. For example, the Gold-Paper explains that when the helicopter is in velocity stabilization mode, the response type changes automatically based on “groundspeed for the pitch, roll and yaw axes.” (DJI-1009, 421.) For example, the “roll response-type **automatically changes modes** from AC/VH [attitude command/velocity hold] to RC/AH [rate command/attitude hold] between 60 and 80 kts.” (DJI-1009, 421; *See* DJI-1009, Figure 2.) Furthermore, “[a]uto-moding of the pitch and roll response-types from velocity command to attitude command occurs when the pilot commands a velocity that exceeds the 5 kt threshold when the pilot applies a large cyclic input.” (DJI-1009, 421.) Additionally, Hover Hold is **automatically** “engage[d] when ground speed, pitch and roll rates, longitudinal and lateral linear acceleration, and pitch and roll stick commands are small.” (DJI-1009, 421.) And while in velocity stabilization mode, “the yaw axis control laws provide **automatic** low speed turn coordination (LSTC) which is enabled above 15

kts groundspeed.” (DJI-1009, 423.) As a final example, Altitude Hold mode “engages **automatically**” when in velocity stabilization mode and Hover Hold mode is entered. (DJI-1009, 423.) To automatically and selectively activate these modes, the “*initialization command logic*” receives sensor input (e.g., speed) and provides command input to the lateral and longitudinal control architectures to enable or disable portions of those architectures to achieve the desired mode of operation—i.e., the “*initialization command logic*” is “*in data communication with the lateral control architecture and in data communication with the longitudinal control architecture*” [1C.4].

152. For these additional reasons, the combination of Gold, Shue and Gold-Paper discloses “*the initialization command logic selectively activates the lateral control architecture for controlling the lateral motion of the aircraft and selectively activates the longitudinal control architecture for controlling the longitudinal motion of the aircraft*” [1D].

6. “Control Speed Variations ... While the Aircraft Maintains a Constant Vector Heading Across a Ground Surface” [1E]

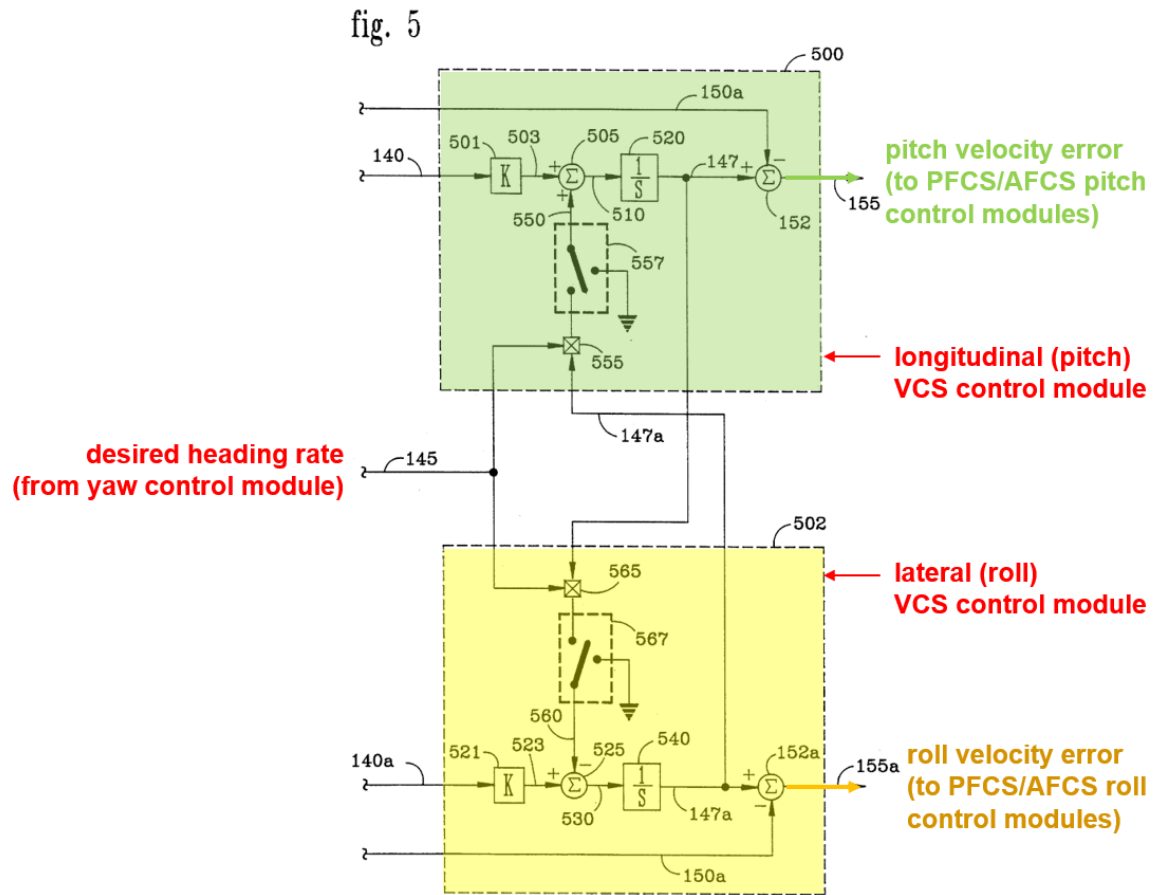
153. Limitation [1E] recites “*the control system utilizes the lateral control architecture and the longitudinal control architecture to control speed variations of the aircraft while the aircraft maintains a constant vector heading across a ground surface.*” Aside from the abstract and claims, the ’082 patent does not use

the terminology “*constant vector heading across a ground surface*.” The ’082 patent instead refers to a “constant vector” throughout the detailed description. (See, e.g., DJI-1001, 2:36-39 (“enable a pilot to use the directional controller to command flat yawing turns at low groundspeeds, while maintaining a **constant vector across the ground**”); 7:45-47 (“This design enables the pilot to command and hold any crab angle around the 360 degree circle, while the aircraft continues to move across the ground on a **constant vector**”).) The term “*constant vector heading across a ground surface*” is also not a term of art.

154. Solely for purposes of this proceeding, I consider the “*constant vector heading across a ground surface*” to be the straight-line ground track or course of the aircraft at a constant speed. Accordingly, under this interpretation, an “*aircraft maintain[ing] a constant vector heading across a ground surface*” means the aircraft flies relative to the ground in a fixed direction at a constant speed.

155. Gold discloses “*utiliz[ing] the lateral control architecture and the longitudinal control architecture to control speed variations of the aircraft while the aircraft maintains*” a constant flight (ground track) at a specific speed (“*a constant vector heading across a ground surface*”). Gold explains that the “command model for the yaw axis provides a desired yaw axis rate response, i.e., desired heading rate, on a line 145 to the velocity model 143.” (DJI-1005, 5:11-

13.) The velocity command system, illustrated in annotated Figure 5 below, “uses the heading rate signal on the line 145 and the desired attitude response for the pitch axis and the yaw axis to develop centrifugal acceleration terms.” (DJI-1005, 5:15-20.) To hold the flight path (inertial) referenced velocities constant, “centrifugal acceleration terms which are caused by the pilot yawing the vehicle must be included in the pitch axis and roll axis velocity models.” (DJI-1005, 6:35-38.) A longitudinal centrifugal acceleration term is provided on line 550 to the summing junction 505 and a lateral centrifugal acceleration term is provided on line 560 to summing junction 525. (DJI-1005, 5:38-40, 5:48-51; Figure 5.) The acceleration terms are provided to integrators 520, 540 which produce desired pitch and roll velocity signals, respectively. (See DJI-1005, 6:7-10.) A summing junction compares the command velocity with the actual velocity (ground speed) to produce pitch and roll velocity error signals. (See DJI-1005, 6:10-15.)



Gold, Annotated Figure 5

156. The resulting error signals are provided on lines 155 and 155a to the pitch (longitudinal) and roll (lateral) control modules of the AFCS and PFCS which “drive the velocity error to zero” in both the lateral and longitudinal axes. (See DJI-1005, Figure 4; 6:15-17.) The longitudinal and lateral control architectures control speed variations of the aircraft by driving the longitudinal and lateral velocity errors to zero and maintain the aircraft on a “*constant vector heading across a ground surface*” (straight-line flight path at a constant speed).

157. Thus, the combination of Gold, Shue, and Gold-Paper discloses *“utiliz[ing] the lateral control architecture and the longitudinal control architecture to control speed variations of the aircraft while the aircraft maintains”* a constant flight (track) at a specific speed (*“a constant vector heading across a ground surface”*).

C. Independent Claim 11

158. The combination of Gold, Shue, and Gold-Paper renders claim 11 obvious. I reproduce claim 11 below with labels added for ease of discussion.

[11P] A method to control flat yawing turns of an aircraft while maintaining a constant vector heading across a ground surface, the method comprising:

[11A] sensing the speed variation of the aircraft with a sensor carried by the aircraft, the speed variation having:

- a longitudinal direction of motion; and
- a lateral direction of motion;

[11B] providing a control system in data communication with the aircraft sensor and operably associated with the actuators, the control system having:

- [11B.1]** a model;
- [11B.2]** a lateral control architecture;
- [11B.3]** a longitudinal control architecture;

[11B.4] an initialization command logic in data communication with the lateral control architecture and in data communication with the longitudinal control architecture;

[11C] decoupling the directional movement of the aircraft into the lateral equation of motion and the longitudinal equation of motion with the model;

[11D] controlling the lateral direction of motion with a lateral control architecture, the lateral control architecture utilizing the lateral equation of motion;

[11E] controlling the longitudinal direction of motion with a longitudinal control architecture, the longitudinal control architecture utilizing the longitudinal equation of motion; and

[11F] selectively activating the lateral control architecture and the longitudinal control architecture with the initialization command logic;

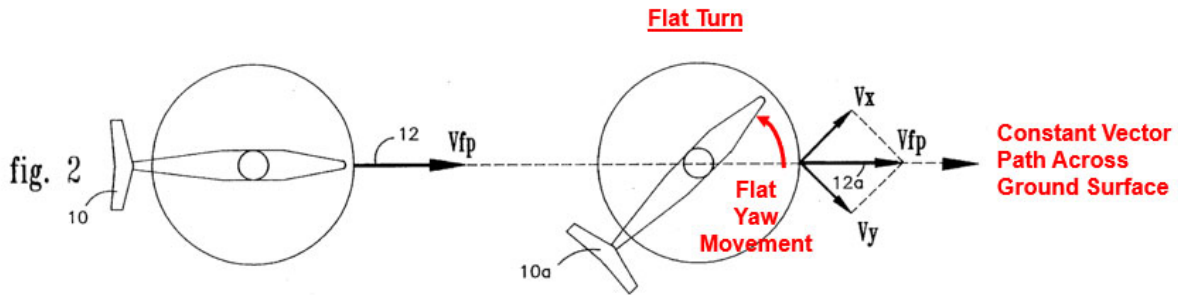
[11G] wherein the control system receives sensed speed variation data from the sensor and operably controls the actuators, thus providing selective control of the yawing turns of the aircraft while maintaining a constant vector across a ground surface.

1. Preamble [11P]

159. The combination of Gold, Shue, and Gold-Paper discloses a “*method to control flat yawing turns of an aircraft while maintaining a constant vector heading across a ground surface*” [11P]. Gold’s PFCS and AFCS each contain a

control module for controlling yaw. (DJI-1005, 3:17-18.) Gold explains that the “command model for the yaw axis provides a desired yaw axis rate response, i.e., desired heading rate, on a line 145 to the velocity model 143.” (DJI-1005, 5:9-13.) In response to a pilot’s yaw command during operation in velocity stabilization mode, “the aircraft 10a yaws while maintaining a constant flight path reference velocity 12a with respect to an inertial frame of reference.” (DJI-1005, 2:60-64; *see also*, DJI-1005, 1:51-55 (“Another object of the present invention is to provide an aircraft velocity command system which allows the pilot, during operation in a velocity stabilization mode, to yaw the aircraft from side to side without changing the inertial flight path of the aircraft”).) When in Gold’s velocity stabilization mode, Gold’s flight control system automatically adjusts pitch and roll attitude to keep the aircraft moving in the same direction at a constant speed. (*See, e.g.*, DJI-1005, 5:9-6:57.)

160. The yaw movement controlled by Gold and illustrated in annotated Figure 2 is a “*flat yawing turn*” (bank angle is zero) because during the movement the aircraft rotates about its vertical axis (turning the nose of the aircraft) without pitching or rolling to any significant degree that would induce lateral or longitudinal motion and drive the aircraft off its constant velocity path.



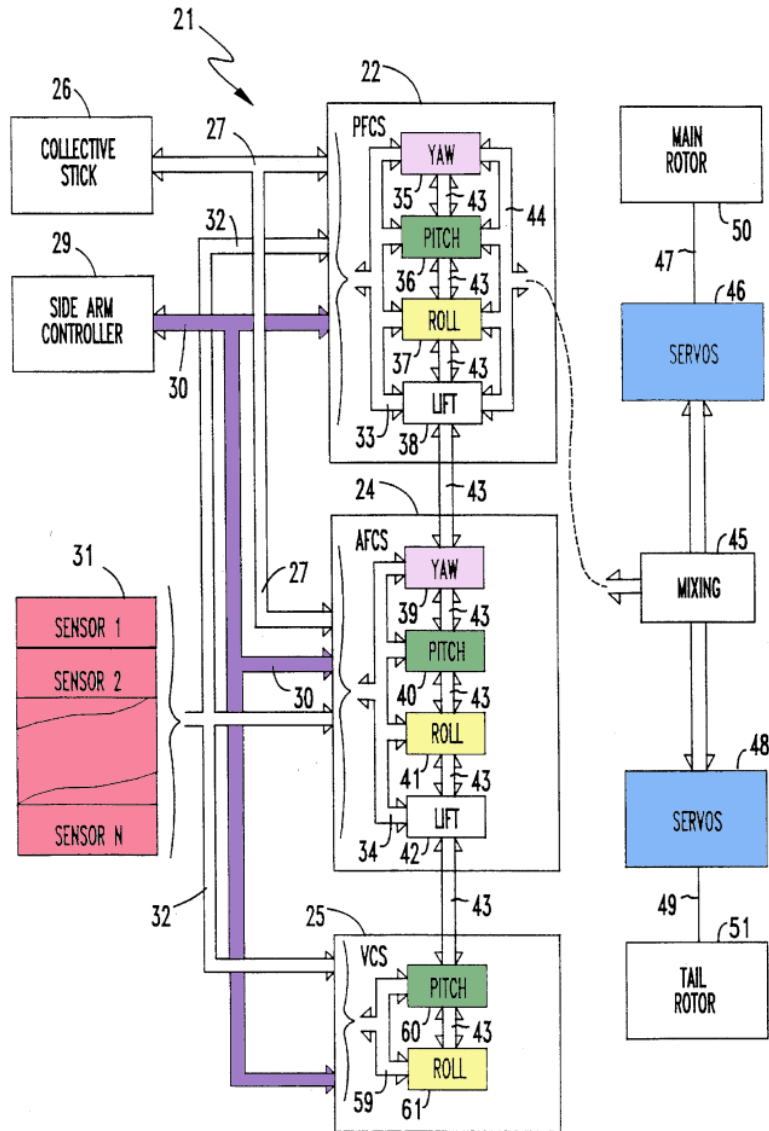
Gold, Annotated Figure 2

161. Thus, the combination of Gold, Shue, and Gold-Paper discloses a “method to control flat yawing turns of an aircraft while maintaining a constant vector heading across a ground surface” [11P].

2. “Sensing” Limitation [11A]

162. Gold discloses “sensing the speed variation of the aircraft with a sensor carried by the aircraft, the speed variation having a longitudinal direction of motion; and a lateral direction of motion” [11A]. The PFCS, AFCS, and VCS of flight control system 21 receive “sensed parameter signals from sensors 31 [shaded red in annotated Gold Figure 3 below] on lines 32.” (DJI-1005, 3:10-13, 3:39-41.) These sensed parameter signals provide “the PFCS and AFCS with the aircraft’s angular rate and attitude response to the main rotor and tail rotor command signals.” (DJI-1005, 3:32-35.) The sensors further provide “information related to velocity, altitude, acceleration, etc.” (DJI-1005, 3:35-36.) For example, the longitudinal groundspeed and lateral groundspeed are provided to the VCS from

the sensors. (DJI-1005, 5:23-26, Figure 4.) The longitudinal groundspeed signal provides the sensed variation of “*a longitudinal direction of motion*” and the lateral ground speed signal provides the sensed variation of “*a lateral direction of motion*.” Additionally, sensors measuring acceleration “*sense[] speed variation of the aircraft*” because acceleration is a measurement of how speed varies. (See, e.g., §III.A.2 (describing IMUs having accelerometers as sensors).)



Gold, Annotated Figure 3

163. Additionally, U.S. Patent 5,238,203 to Skonieczny, et al.

(“Skonieczny”), which is incorporated by reference into Gold, provides an exemplary list of sensed aircraft parameters: “actual airspeed (line 60), actual yaw rate (line 64), pitch attitude (line 86), bank angle (PHI) (line 87), roll rate (line 88),

lateral acceleration (line 89), heading (line 90), longitudinal ground speed (line 91), and lateral ground speed (line 92).” (DJI-1006, 4:48-53; DJI-1005, 4:38-43 (incorporating Skonieczny by reference).)

164. Thus, Gold discloses “*sensing the speed variation of the aircraft with a sensor carried by the aircraft, the speed variation having a longitudinal direction of motion; and a lateral direction of motion*” [11A].

3. “Providing a Control System” Limitation [11B]

165. Claim 11 recites “*providing a control system in data communication with the aircraft sensor and operably associated with the actuators*” [11B]. This limitation is substantially the same as limitation [1C] (“*a control system in data communication with the aircraft sensor and operably associated with the actuators*”). Thus, for the reasons I discussed above in §IV.B.3, the combination of Gold, Shue, and Gold-Paper teaches this limitation.

a. “Model” [11B.1]

166. Claim 1 recites that the “*control system*” includes a “*model*” [1C.1]. Thus, for the reasons I discussed above in §IV.B.4.a, the combination of Gold, Shue, and Gold-Paper discloses “*the control system*” has “*a model*” [11B.1].

b. “Lateral Control Architecture” [11B.2]

167. Claim 1 recites that the “*control system*” includes “*a lateral control architecture*” [1C.2]. Thus, for the reasons I discussed in §§IV.B.4.c, d, the

combination of Gold, Shue, and Gold-Paper discloses “*the control system*” has “*a lateral control architecture*” [11B.2].

c. “Longitudinal Control Architecture” [11B.3]

168. Claim 1 recites that the “*control system*” includes “*a longitudinal control architecture*” [1C.3]. Thus, for the reasons I discussed in §§IV.B.4.b, d, the combination of Gold, Shue and Gold-Paper discloses “*the control system*” has a “*longitudinal control architecture*” [11B.3].

d. “Initialization Command Logic” [11B.4].

Limitation [11B.4] is identical to limitation [1C.4]. For the reasons I discussed in §IV.B.5, the combination of Gold, Shue, and Gold-Paper discloses “*an initialization command logic in data communication with the lateral control architecture and in data communication with the longitudinal control architecture*” [11B.4].

4. “Decoupling the Directional Movement of the Aircraft” [11C]

169. Claim 1 recites that the “*model*” in the “*control system*” is adapted to “*decouple the directional movement of the aircraft into a lateral equation of motion and a longitudinal equation of motion.*” Thus, for the reasons I discussed in §§IV.B.4.a, d, the combination of Gold, Shue, and Gold-Paper discloses “*decoupling the directional movement of the aircraft into the lateral equation of motion and the longitudinal equation of motion with the model*” [11C].

5. “Controlling the Lateral” and “Longitudinal Direction of Motion” Limitations [11D] and [11E]

170. Limitations [11D] and [11E] recite overlapping subject matter with limitations [1C.2] and [1C.3]. Thus, for the reasons discussed in §§IV.B.4, b-d, the combination of Gold, Shue, and Gold-Paper discloses limitations [11D] and [11E].

Claim 1	Claim 11
[1C.2] a lateral control architecture in data communication with the model, the lateral control architecture being adapted to utilize the lateral equation of motion to control the lateral motion of the aircraft	[11D] controlling the lateral direction of motion with a lateral control architecture, the lateral control architecture utilizing the lateral equation of motion
[1C.3] a longitudinal control architecture in data communication with the model, the longitudinal control architecture adapted to utilize the longitudinal equation of motion to control the longitudinal motion of the aircraft	[11E] controlling the longitudinal direction of motion with a longitudinal control architecture, the longitudinal control architecture utilizing the longitudinal equation of motion

6. “Selectively Activating” [11F]

171. Claim 1 recites that “*the initialization command logic selectively activates the lateral control architecture for controlling the lateral motion of the aircraft and selectively activates the longitudinal control architecture for controlling the longitudinal motion of the aircraft*” [1D]. Limitation [11F] is substantially the same as limitation [1D] (“*selectively activating the lateral control*

architecture and the longitudinal control architecture with the initialization command logic”). Thus, for the reasons I discussed in §IV.B.5, the combination of Gold, Shue, and Gold-Paper discloses limitation [11F].

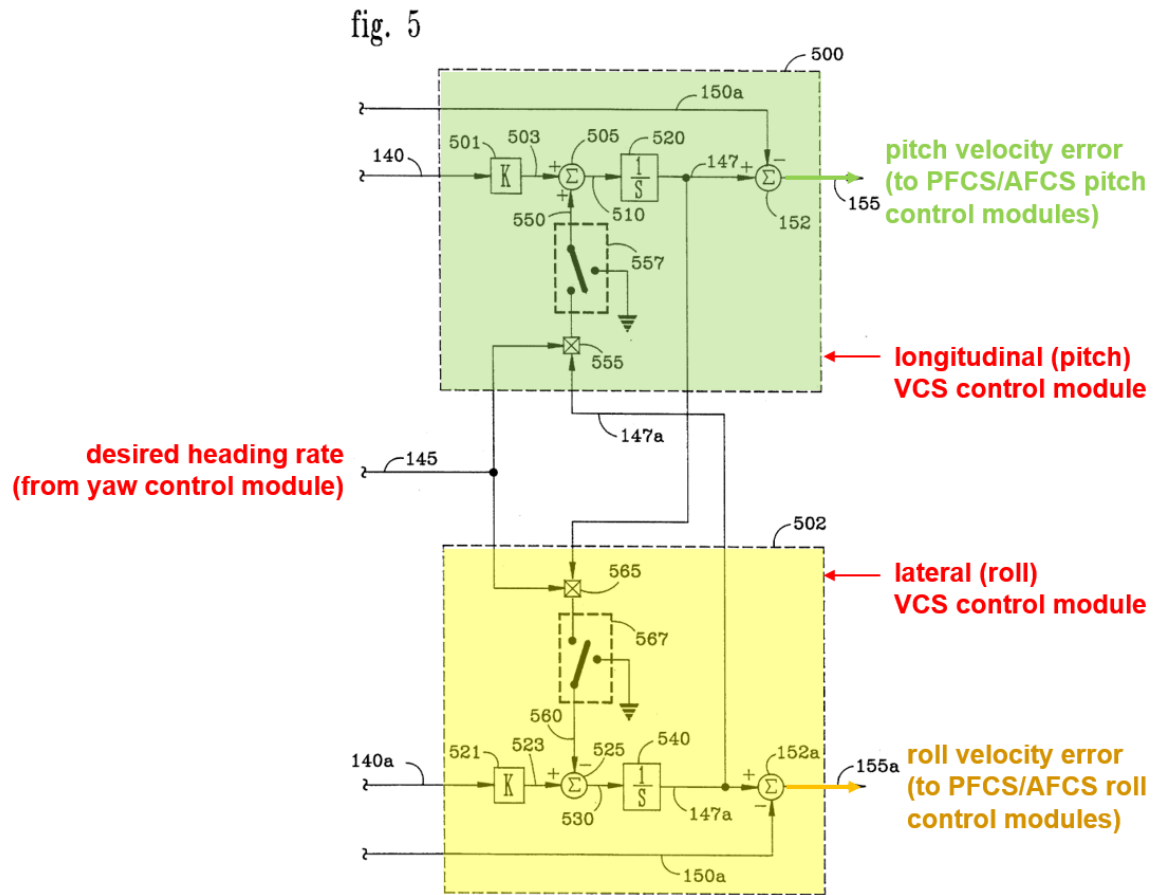
7. “Selective Control of the Yawing Turns” [11G]

172. Limitation [11G] recites that “*control system receives sensed speed variation data from the sensor and operably controls the actuators, thus providing selective control of the yawing turns of the aircraft while maintaining a constant vector across a ground surface.*” As I discussed in §IV.C.1, Gold discloses “*control[ling] flat yawing turns of an aircraft while maintaining a constant vector heading across a ground surface*” [11P]. I note that the specification of the ’082 patent does not describe the recited “*selective* control of yawing turns ... while maintaining a constant vector flat turn relative to a ground surface.” At most, the ’082 patent discloses that a pedal input by the pilot initiates and controls yaw movement. (*See, e.g.,* DJI-1001, 3:64-4:5.) The ’082 patent further discloses that “the control laws will automatically adjust pitch and roll attitude to keep the aircraft moving in the same direction at a constant speed whenever the pilot inputs a directional command at low speed.” (DJI-1001, 2:42-45.)

173. Regardless of the lack of description provided in the ’082 patent, Gold discloses this limitation. In Gold, “[i]n response to a yaw command by a pilot

during operation in a velocity stabilization mode, the aircraft 10a yaws while maintaining a constant flight path reference velocity 12a with respect to an inertial frame of reference.” (DJI-1005, 2:61-64.) When in velocity stabilization mode, Gold’s flight control system automatically adjusts pitch and roll attitude to keep the aircraft moving in the same direction at a constant speed, as I discussed in §§IV.B.6, IV.C.1. In Gold, like the ’082 patent, the pilot selectively initiates a yaw maneuver using the controller and in response to these selections, Gold’s flight control system automatically provides “*control of the yawing turns of the aircraft while maintaining a constant vector across a ground surface.*”

174. As shown in annotated Figure 5 below, as part of adjusting the pitch and roll attitude, the longitudinal and lateral ground speeds (the “*sensed speed variation data*”) are received from sensors 31 on the lines labeled 150a in Figure 5. (See, DJI-1005, 6:30-31.) The sensed values are compared with the desired pitch and roll axis command signals to provide pitch and roll axis velocity error signals on lines 155 and 155a. (See DJI-1005, 6:32-33.)

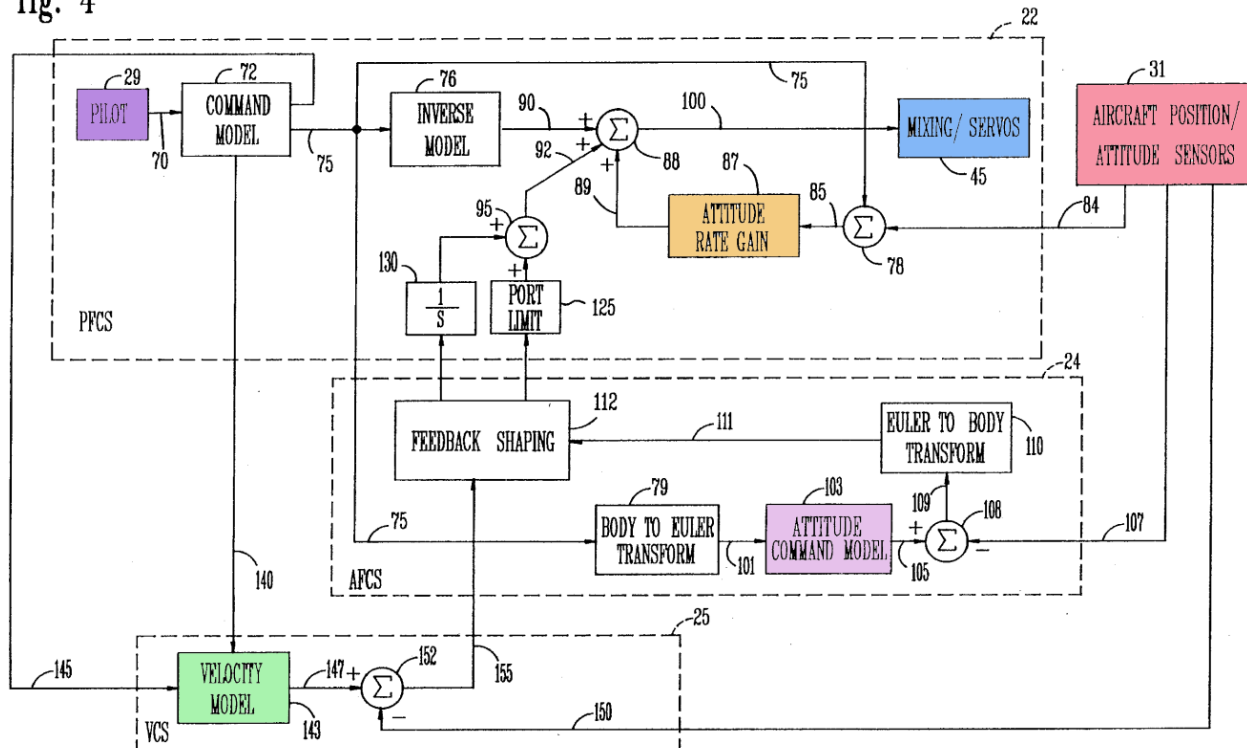


Gold, Annotated Figure 5

175. When the system is in velocity stabilization mode, feedback shaping circuitry 112 in the AFCS (shown in annotated Figure 4 below) provides the velocity error signal on the integral path and “a combination of attitude feedback signals and velocity error signals to the proportional path.” (DJI-1005, 5:37-42.) The output of each is provided to a summing junction 95 in the PFCS controller whose output, in turn, is provided to summing junction 88. The output of summing junction 95 is a command modifying signal 92. (See DJI-1005, 4:27-28.) Summing

junction 88 also receives a control command signal from inverse model 76 representing the approximate rotor command necessary to achieve the desired response. (See DJI-1005, 4:9-11.) The output of summing junction 88 is provided on line 100 to mixing function 45 which commands displacement of mechanical servos and linkages (actuators).

fig. 4



Gold, Annotated Figure 4

176. Thus, the combination of Gold, Shue, and Gold-Paper discloses that the “*control system receives sensed speed variation data from the sensor and operably controls the actuators, thus providing selective control of the yawing*

turns of the aircraft while maintaining a constant vector across a ground surface”
[11G].

D. Dependent Claims

1. “Directional Controller” (Claims 2 and 12)

177. Claims 2 and 12, reproduced below, recite subject matter directed to a “*directional controller*.” I note that claim 12 associates the directional controller with control of yaw movement. The combination of Gold, Shue, and Gold-Paper renders these claims obvious.

2. The aircraft of claim 1, the aircraft further comprising:
a directional controller, the directional controller being manipulated by a pilot controlling the aircraft, the directional controller being in data communication with the control system.

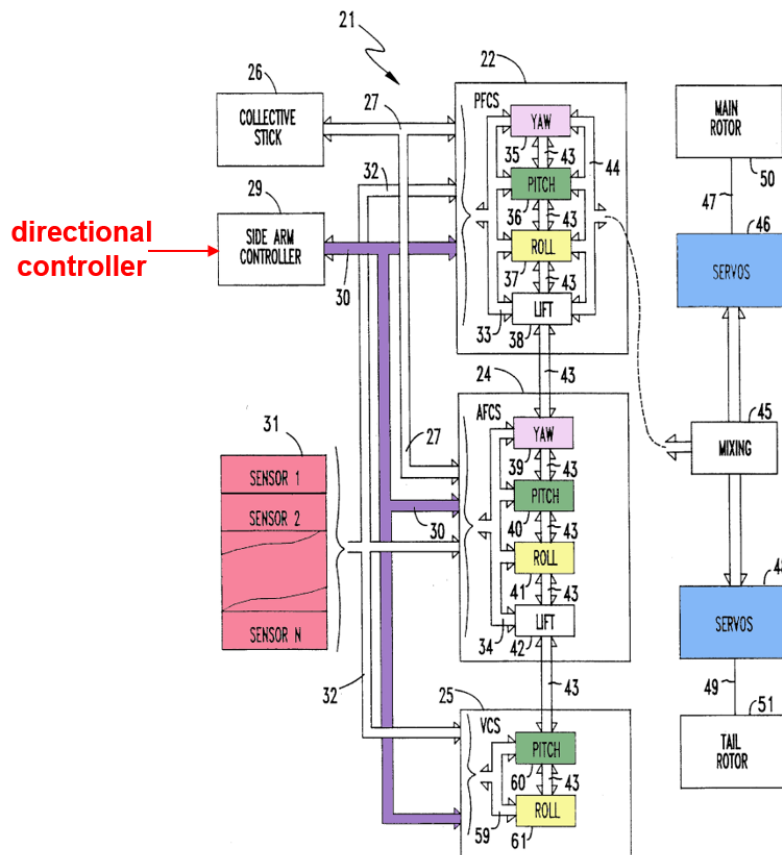
12. The method of claim 11, the method further comprising:
commanding the flat yawing turns with a directional controller manipulated by a pilot controlling the aircraft, the directional controller being operably associated with a directional control architecture, the directional control architecture being in data communication with the control system.

178. Input devices manipulated by a pilot to control movement of an aircraft in the yaw direction were extremely well known before the earliest possible priority date of the ’082 patent, as I discussed in §III.A.1. In fact, every

rotary aircraft operated by a pilot at the time of the '082 patent had a yaw controller. The '082 patent describes that in its system “a lateral controller, longitudinal controller, and directional controller are characterized as petal [sic] 203 or similarly suited devices.” (DJI-1001, 4:2-5.) The '082 patent further notes that its methods for aircraft guidance can be applied to “traditional cockpit layouts with a center stick for longitudinal and lateral control, pedals for directional control, and a collective stick for vertical control, as well as more advanced designs which combine multiple control axes into a center or side stick controller.” (DJI-1001, 4:22-30.) Thus, the '082 patent recognizes that the same physical input device acts as a yaw controller, a lateral controller, a longitudinal controller, and a vertical controller. Gold discloses such a multiple axis control device—a sidearm controller.

179. The PFCS, AFCS, and VCS of Gold’s flight control system receive command signals from sidearm controller 29, as shown in the annotated version of Figure 3 below. (DJI-1005, 3:10-12.) Specifically, **“yaw axis command signals are generated by the pilot's lateral twisting (left or right) of the sidearm controller**, pitch axis command signals are generated by the pilot's pushing and pulling (front or back) of the sidearm controller, and roll axis command signals are generated by the pilot applying a left or right force to the sidearm controller.” (DJI-

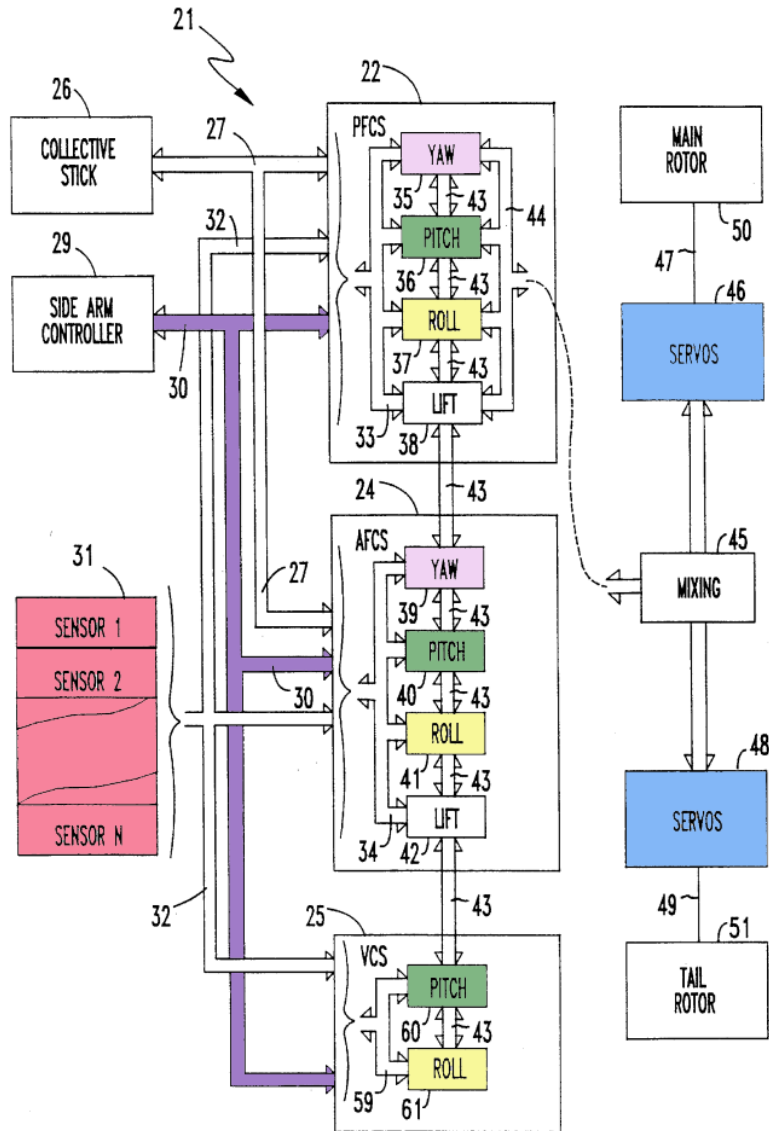
1005, 3:64-4:4.) Because the sidearm controller controls yaw movements, Gold’s sidearm controller is a “*directional controller*” that is “*manipulated by a pilot controlling the aircraft*” and is “*in data communication with the control system*” [2].



Gold, Annotated Figure 3

180. Therefore, Gold discloses “*a directional controller, the directional controller being manipulated by a pilot controlling the aircraft, the directional controller being in data communication with the control system*” [2].

181. Gold discloses a “*directional control architecture*” [12]. The PFCS and AFCS of Gold’s flight control system 21 each contains a control module (35, 39) for controlling yaw (shaded pink in the annotated version of Gold Figure 3 below). (DJI-1005, 3:17-18.) Therefore, Gold’s flight control system has 2 yaw control modules. Because they control movement of the aircraft in the yaw direction in response to pilot commands provided via the sidearm controller, yaw control module 35 of PFCS and yaw control module 39 of the AFCS are collectively part of “*a directional control architecture*” of the flight control system which is “*operably associated*” with the “*directional controller*” (sidearm controller) and is “*in data communication with the control system.*”



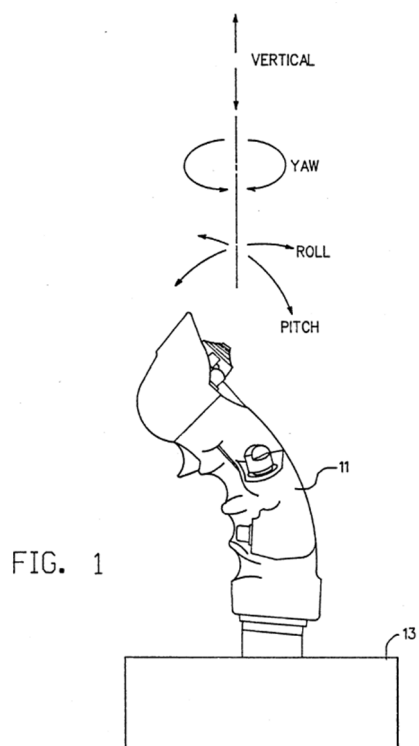
Gold, Annotated Figure 3

182. Gold explains that “[i]n response to a yaw command by a pilot during operation in a velocity stabilization mode, the aircraft 10a yaws while maintaining a constant flight path reference velocity 12a with respect to an inertial frame of reference.” (DJI-1005, 2:60-64.) Gold’s Figure 2 shows “the response of a

vehicle to a pilot yaw command during operation in a velocity stabilization mode.” (DJI-1005, 2:34-36.) The yaw movement commanded by the pilot is a “*flat yawing turn*” as discussed in §IV.C.1 and illustrated in Figure 2.

183. Thus, Gold discloses “*commanding the flat yawing turns with the directional controller manipulated by a pilot controlling the aircraft, the directional controller being operably associated with a directional control architecture, the directional control architecture being in data communication with the control system*” [12].

184. Moreover, four-axis sidearm controllers, manipulated by a pilot, that command a yaw movement, were well-known before the earliest priority date of the '082 patent. For example, Figure 1 of U.S. Patent 5,001,646 to Caldwell, et al., issued March 19, 1991, depicts such a four-axis controller showing the control movements for vertical, yaw, pitch, and roll control. (See DJI-1014, 2:52-55; Figure 1 below.)



Caldwell, Figure 1

2. “*Lateral Control Architecture*” (Claims 5 and 15)

185. Claims 5 and 15 are reproduced below:

5. The aircraft of claim 1, the lateral control architecture comprising:

- [5A] a lateral sideward groundspeed control loop;
- [5B] a lateral roll attitude control loop; and
- [5C] a lateral roll rate control loop.

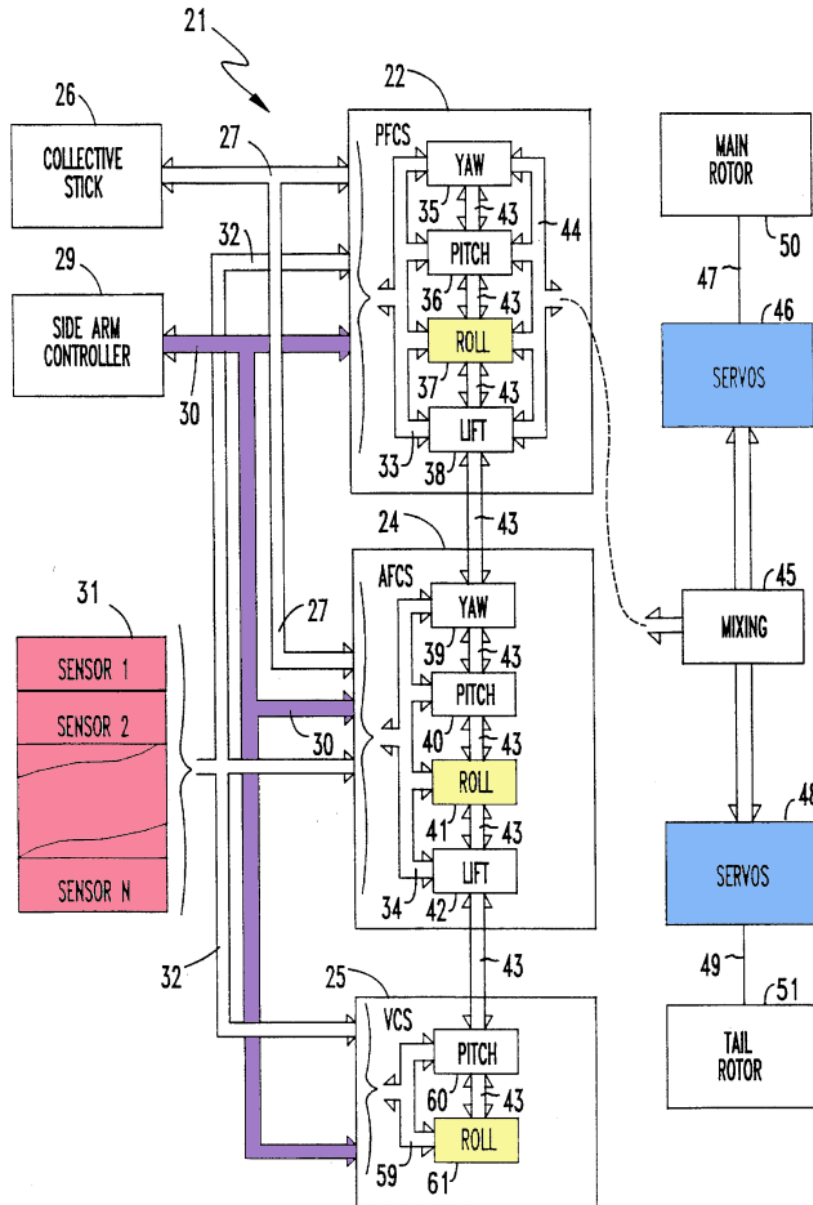
15. The method of claim 11, wherein controlling the lateral direction of motion with the lateral control architecture comprises:

- [15A] communicating lateral motion data through a lateral sideward groundspeed control loop;

[15B] communicating lateral motion data through a lateral roll attitude control loop; and

[15C] communicating lateral motion data through a lateral roll rate control loop.

186. As discussed in §IV.B.4.c and illustrated in annotated Figure 3 below, Gold's flight control system includes a “*lateral control architecture*” having 3 roll control modules (shaded yellow). As I describe below, the “*lateral control architecture*” includes “*a lateral sideward groundspeed control loop*” [5A]/[15A], “*a lateral roll attitude control loop*” [5B]/[15B] and “*a lateral roll rate control loop*” [5C]/[15C].



Gold, Annotated Figure 3

a. “Lateral Sideward Groundspeed Control Loop” [5A]/[15A]

187. Gold discloses a “lateral sideward groundspeed control loop” [5A]/[15A]. VCS 25 of Gold’s flight control system 21 “contains control channel modules for providing pitch axis and **roll axis** velocity error signals to the AFCS.”

(DJI-1005, 3:45-46.) When operating in velocity stabilization mode, VCS roll error signals “are fed back through PFCS proportional and integral paths to drive the error signals to zero.” (DJI-1005, 3:50-52.)

188. Gold’s Figure 4 illustrates the functional interconnection of the control system, while Figure 5 shows greater detail of VCS 25 for the roll axis. (DJI-1005, 3:54-55.) Gold describes Figure 4 with respect to pitch axis modules 36, 40, 60 but, as explained by Gold, “the functional interconnection of FIG. 4 is equally applicable to flight control roll attitude reference and VCS roll axis velocity error signals.” (DJI-1005, 3:54-61.) In the figure below, which I have labeled Figure A, I have modified Figure 4 to incorporate the roll axis velocity control module excerpted from Figure 5 and its interconnections to the components of Figure 4. The details provided by Figure 5 appear at the bottom of Figure 4, as shown below.

fig. 4

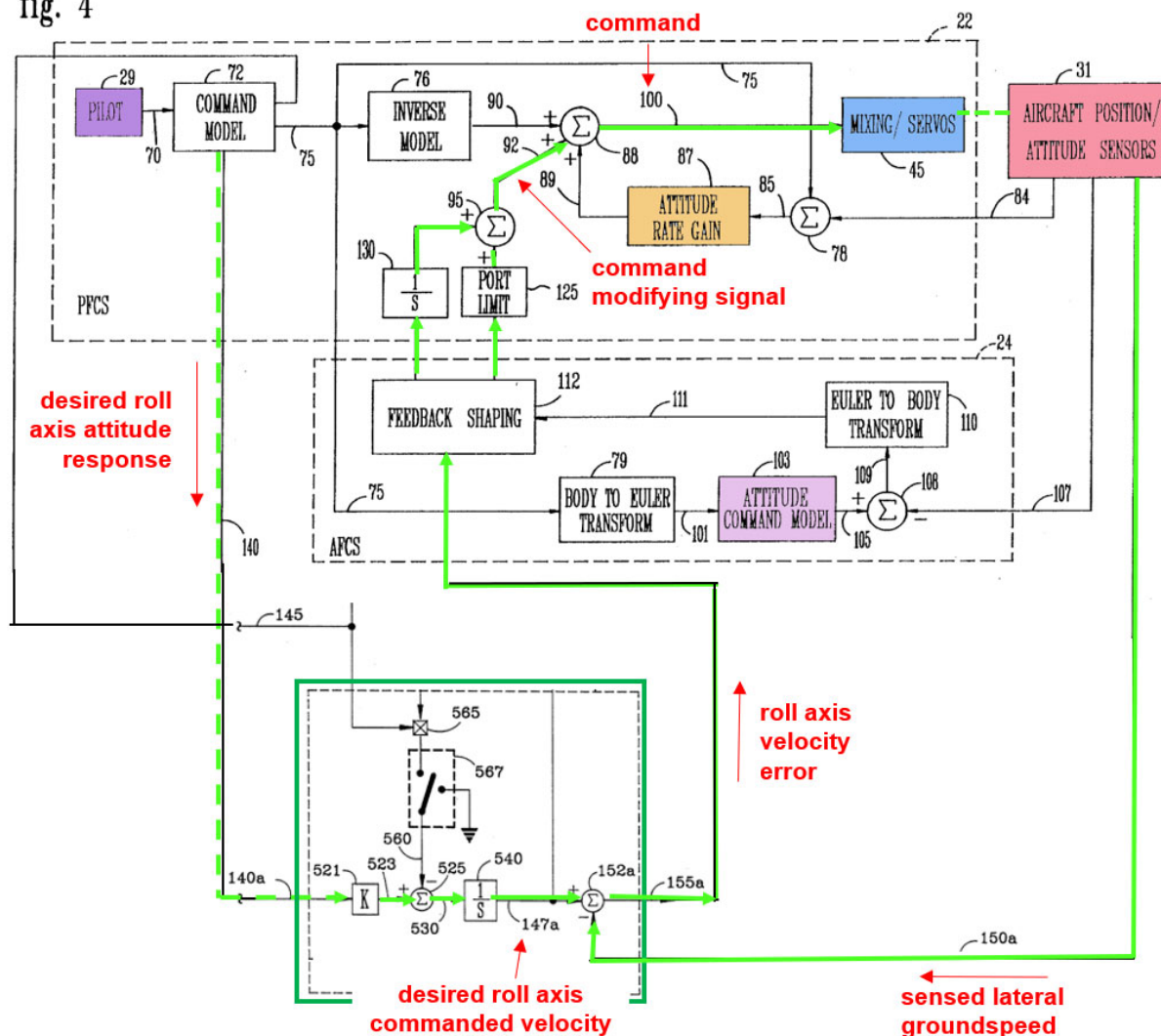


Figure A

189. In roll axis velocity control module 502 (indicated by the green box in Figure A above), the desired roll axis attitude response required to maintain the desired velocity in velocity stabilization mode is provided on line 140a from the command model to a gain function 521 in the VCS where it is multiplied by the gravitational constant to produce an acceleration term which is provided to

summing junction 525. (DJI-1005, 6:21-25.) The summing junction also receives a lateral centrifugal acceleration term on line 560 when the aircraft is operating in velocity stabilization mode. (DJI-1005, 6:48-50.) The output of summing junction 525 is provided to integrator 540, the output of which “is a desired roll axis commanded velocity signal on the line 147a.” (DJI-1005, 6:27-30.) The desired roll axis commanded velocity signal and the lateral **ground speed** 150a received from sensors 31 are provided to summing junction 152a. (DJI-1005, 6:30-31.) The summing junction 152a compares the desired roll axis signal commanded velocity with the lateral ground speed signal fed back from the sensors and provides as its output a “roll axis velocity error signal” on line 155a to the AFCS. (DJI-1005, 6:32-33.)

190. When the system is in velocity stabilization mode, feedback shaping circuitry 112 in the AFCS provides the roll axis (lateral) velocity error signal on the integral path and “a combination of attitude feedback signals and velocity error signals to the proportional path.” (DJI-1005, 5:37-42.) The output of each is provided to a summing junction 95 in the PFCS roll (lateral) controller whose output, in turn, is provided to summing junction 88. The output of summing junction 95 is a command modifying signal 92. (*See* DJI-1005, 4:27-28.) Summing junction 88 also receives a control command signal from inverse model 76

representing the approximate rotor command necessary to achieve the desired roll rate of change. (See DJI-1005, 4:9-11.) The output of summing junction 88 is provided on line 100 to mixing function 45 which commands displacement of mechanical servos and linkages. (DJI-1005, 3:25-29.) The sensors, in turn, provide the roll (lateral) control modules, including the roll (lateral) control module of the VCS, with the aircraft's response to the rotor command signals. (See DJI-1005, 3:32-35.) As discussed above, this loop controls the lateral (sideward) component of the velocity. Accordingly, as shown in Figure A above, Gold's "*lateral control architecture*" includes a "*lateral sideward groundspeed control loop*" [5A]/[15A].

191. The roll (lateral) axis velocity error determined in the VCS roll control module is "*lateral motion data.*" As discussed above, the roll axis velocity error is provided to the AFCS on line 155a and is subsequently provided to the PFCS (after shaping) through the lateral sideward groundspeed control loop (indicated by the green lines in Figure A above). Thus, Gold discloses "*communicating lateral motion data through a lateral sideward groundspeed control loop*" [15A].

b. "*Lateral Roll Attitude Control Loop*" [5B]/[15B]

192. Gold discloses "*a lateral roll attitude control loop*" [5B]/[15B]. As mentioned above, Gold's Figure 4 "is equally applicable to flight control roll

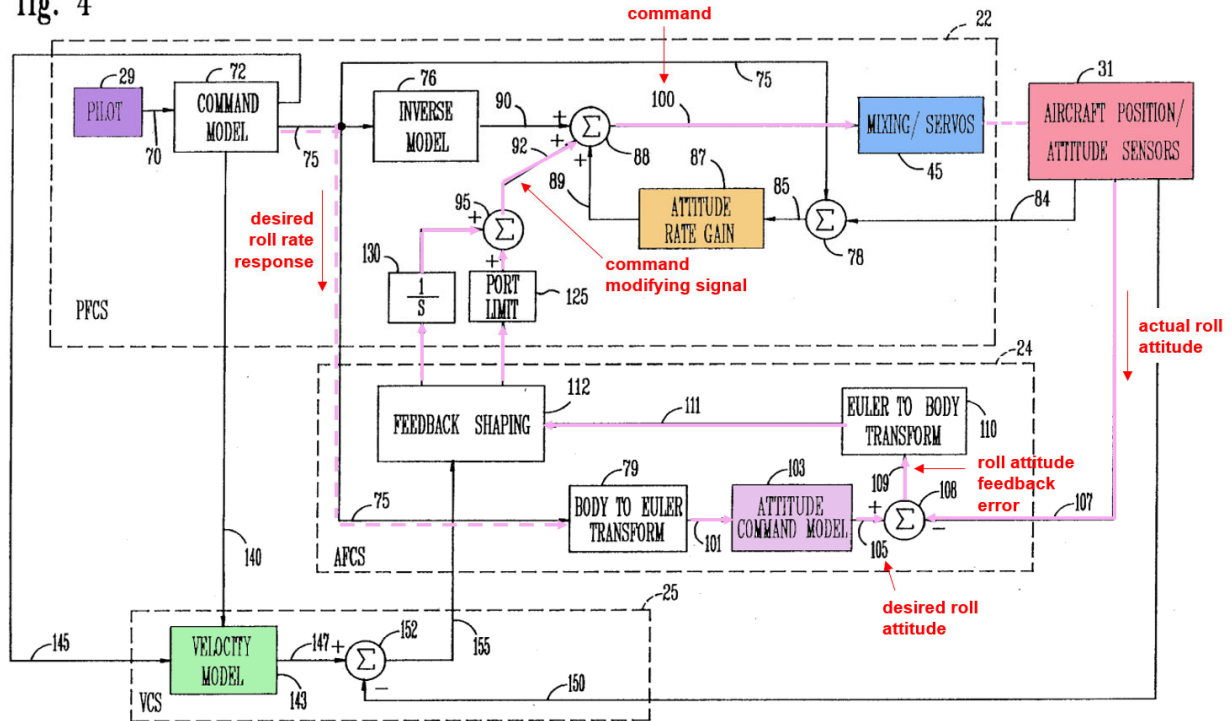
attitude reference and VCS roll axis velocity error signals.” (DJI-1005, 3:60-61.)

Therefore, I describe the operation of the components of Figure 4 with respect to roll (lateral) control. When a pilot applies a left or right force to the sidearm controller, the sidearm controller generates roll (lateral) axis command signals.

(DJI-1005, 4:2-4.) As shown in annotated Figure 4 below, roll command signals from the sidearm controller are provided to command model 72 which shapes the commands “to yield a desired rate and/or attitude response.” (DJI-1005, 4:6-7.)

The desired roll rate response is provided to the Body to Euler Transformation 79 in the roll (lateral) control module of the AFCS and to the inverse model 76 in the roll (lateral) control module of the PFCS. (*See, e.g.*, DJI-1005, 4:15-17.) The Body to Euler transformation output is provided to AFCS attitude command model 103 which includes “an integral function which converts the desired rate response” to a desired roll attitude signal on a line 105. (*See, e.g.*, DJI-1005, 4:50-54.) This desired roll attitude signal is provided to summing junction 108 which also receives the actual roll attitude signal fed back on line 107 from sensors 31. (*See, e.g.*, DJI-1005, 4:54-58.) The output of the summing junction is the roll attitude feedback error signal (in terms of the inertial axes) which is provided to Euler to Body Transform 110 which transforms the roll attitude feedback error signal to aircraft body axes. (*See, e.g.*, DJI-1005, 4:58-63.)

fig. 4



Gold, Annotated Figure 4

193. The roll attitude feedback error signal is applied to feedback shaping circuitry 112 in the roll control module of the AFCS and “thereafter via a proportional path containing a gain function 125 to the summing junction 95” in the roll control module of the PFCS. (See, e.g., DJI-1005, 5:1-4.) The feedback shaping signal is also applied to summing junction 95 via an integral path. (See, e.g., DJI-1005, 5:4-6.) Upon activation of the velocity stabilization mode, “the feedback shaping circuitry replaces the attitude feedback signals with the velocity error signals for the integral path and provides a combination of attitude feedback signals and velocity error signals to the proportional path.” (DJI-1005, 5:37-42.)

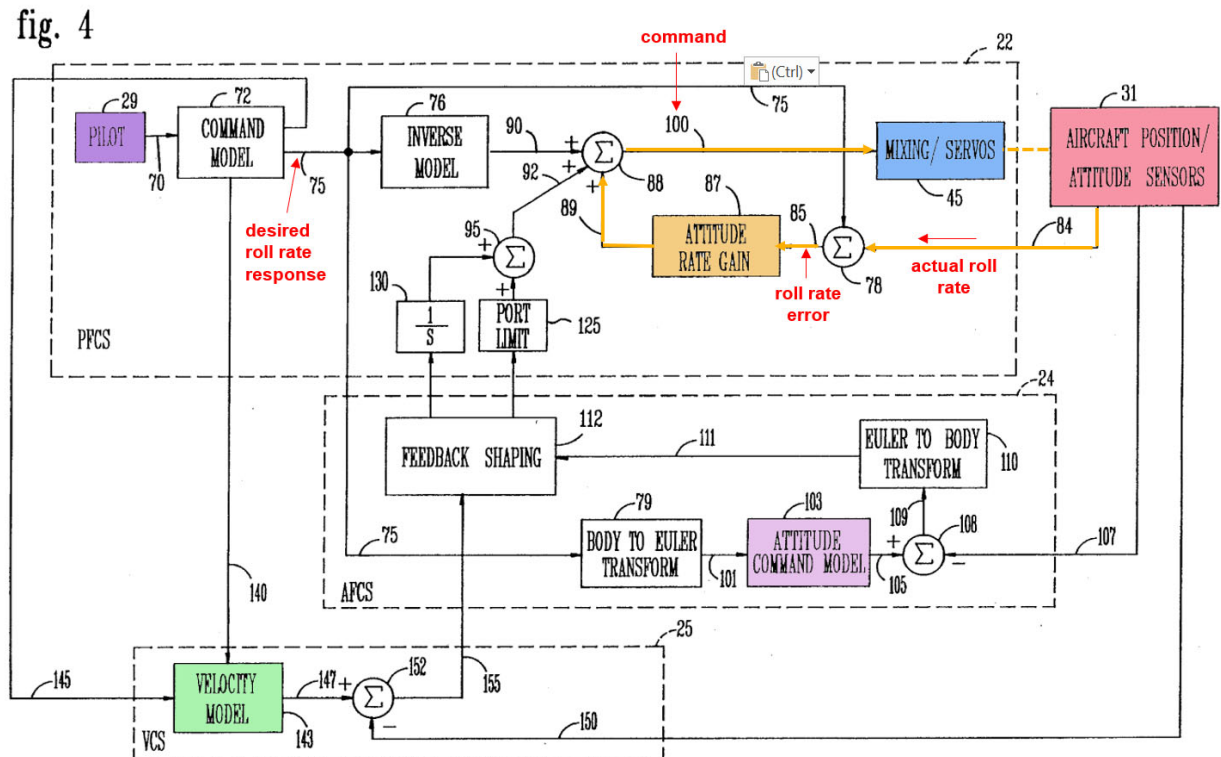
The output of summing junction 95 is the roll command modifying signal on line 92. Summing junction 88 receives this command modifying signal and a control command from inverse model 76 representing the approximate rotor command signal necessary to achieve the desired response. (See DJI-1005, 4:9-11.) The output of summing junction 88 is provided on line 100 to mixing function 45 which commands displacement of mechanical servos and linkages. (DJI-1005, 3:25-29.) The sensors, in turn, sense the response to these commands—creating a feedback loop. As shown in annotated Figure 4 above, Gold’s “*lateral control architecture*” includes a “*lateral roll attitude control loop*” [5B]/[15B].

194. The roll (lateral) attitude feedback error is also “*lateral motion data.*” The roll attitude feedback error signal is communicated from the roll control module of the AFCS to the roll control module of the PFCS through the roll attitude control loop (indicated by pink lines in annotated Figure 4 above). Thus, Gold discloses “*communicating lateral motion data through a lateral roll attitude control loop*” [15B].

c. “*Lateral Roll Rate Control Loop*” [5C]/[15C]

195. Gold discloses “*a lateral roll rate control loop*” [5C]/[15C]. As discussed above, roll (lateral) command signals from the sidearm controller are provided to command model 72 which shapes the commands “to yield a desired

rate” response. (DJI-1005, 4:6-7.) As shown in annotated Figure 4 below which is “equally applicable” to roll control (DJI-1005, 3:60-61), the desired rate response 75 is provided to inverse model 76 of the roll control module in the PFCS which “provides a command signal on a line 90 which represents the approximate rotor command necessary to achieve” the desired roll axis rate of change of the aircraft for each pilot commanded maneuver. (*See, e.g.*, DJI-1005, 4:10-13.)



Gold, Annotated Figure 4

196. The desired rate response on line 75 is also provided to summing junction 78 which compares the desired rate response with the aircraft's actual roll rate provided by sensors 31. (*See, e.g.*, DJI-1005, 4:17-21.) The output of summing

junction 78 is a roll rate error signal on a line 85. (*See, e.g.*, DJI-1005, 4:21-22.)

The roll rate error signal is applied to a proportional gain function 87 (to reduce the error) and the output is provided to summing junction 88. (*See, e.g.*, DJI-1005, 4:22-25.) Summing junction 88 also receives the control command from inverse model 76. (*See, e.g.*, DJI-1005, 4:25-27.) The output of summing junction 88 is provided on line 100 to mixing function 45 which commands displacement of mechanical servos and linkages. (DJI-1001, 3:25-29.) The sensors, in turn, sense the response to these commands—creating a feedback loop. As shown in annotated Figure 4 above, Gold’s “*lateral control architecture*” includes a “*lateral roll rate control loop*” [5C]/[15C].

197. The roll rate error is “*lateral motion data*.” The roll rate error signal is provided through the rate control loop (indicated by orange lines in annotated Figure 4 above) to gain function 87 on a line 85 whose output is provided to summing junction 88, as discussed above. (*See, e.g.*, DJI-1005, 4:21-22.) Thus, Gold discloses “*communicating lateral motion data through a lateral roll rate control loop*” [15C].

3. “*Lateral Controller*” (Claims 6 and 16)

198. Claims 6 and 16, reproduced below, recite subject matter directed to a “*lateral controller*.” Gold discloses the subject matter of these claims.

6. The aircraft of claim 5, further comprising:

[6A] a lateral controller carried by the aircraft, the lateral controller being manipulated by a pilot controlling the aircraft,

[6B] the lateral controller creating a lateral command in data communication with the lateral sideward groundspeed control loop, the lateral roll attitude control loop, and the lateral roll rate control loop.

16. The method of claim 11, the method further comprising:

controlling the lateral direction of motion with a lateral controller manipulated by a pilot controlling the aircraft, the lateral controller being operably associated with the lateral control architecture.

199. Gold's PFCS, AFCS, and VCS receive command signals from sidarm controller 29, as shown in Figure 3. (DJI-1005, 3:10-12.) Specifically, "roll axis command signals are generated by the pilot applying a left or right force to the sidarm controller." (DJI-1005, 3:64-4:4.) Because it controls roll axis (lateral) movement, Gold's sidarm controller 29 is a "*lateral controller carried by the aircraft, the lateral controller being manipulated by a pilot controlling the aircraft*" [6A]. (See DJI-1001, 4:22-30 (recognizing that the same physical input device can act as yaw controller, lateral controller, longitudinal controller, and vertical controller).)

200. The PFCS and AFCS of the flight control system each contain control modules for controlling the roll (lateral) axis of the aircraft. (DJI-1005, 3:17-18.) As discussed in §IV.D.2, roll command signals from the sidearm controller are provided to command model 72 of the flight control system which shapes the command from the controller “to yield a desired rate and/or attitude response.” (DJI-1005, 4:6-7.) This shaped roll command is provided to each of “*the lateral sideward groundspeed control loop, the lateral roll attitude control loop, and the lateral roll rate control loop*” as I discussed in §IV.D.2. Thus, Gold discloses “*the lateral controller creating a lateral command in data communication with the lateral sideward groundspeed control loop, the lateral roll attitude control loop, and the lateral roll rate control loop*” [6B].

201. As discussed above in §IV.D.2, roll command signals from the sidearm controller are provided to command model 72 associated with the roll control module of the “*lateral control architecture*” which shape the commands “to yield a desired rate and/or attitude response.” (DJI-1005, 4:6-7.) In response to a roll (lateral) command from the pilot, the roll control module of the “*lateral control architecture*” generates and “provide[s] rotor command signals” to “a rotor mixing function 45 which commands displacement of mechanical servos 46 and linkages 47 to control the tip path plane of a main rotor 50.” (DJI-1005, 3:25-29;

See §IV.D.2.) As I discussed above in §III.A.1, 4, tilting the tip path plane of the main rotor sideways induces lateral movement. Thus, Gold discloses “*controlling the lateral direction of motion with a lateral controller manipulated by a pilot controlling the aircraft, the lateral controller being operably associated with the lateral control architecture*” [16].

4. “Longitudinal Control Architecture”

202. Claims 8 and 18, reproduced below, are directed to the “*longitudinal control architecture*.” Gold discloses the subject matter of these claims.

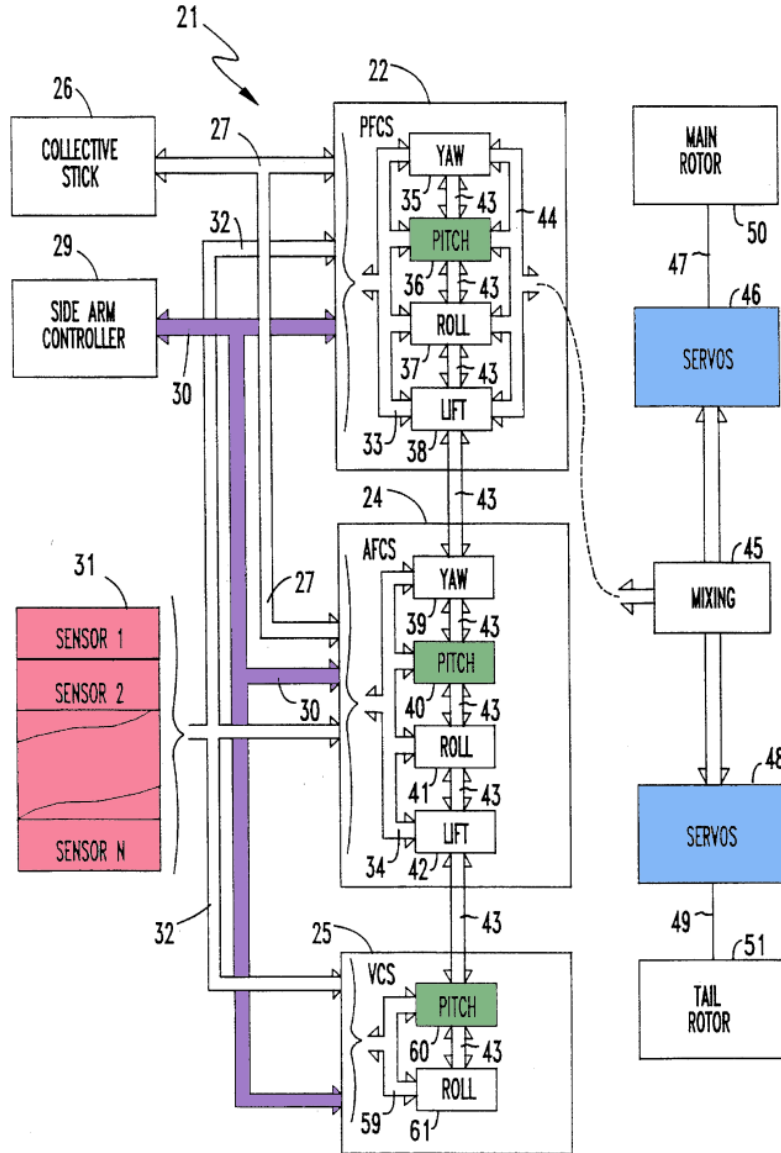
8. The aircraft of claim 1, the longitudinal control architecture comprising:

- [8A] a longitudinal forward speed control loop;
- [8B] a longitudinal pitch angle control loop; and
- [8C] a longitudinal pitch rate control loop.

18. The method of claim 17, wherein controlling the longitudinal direction of motion with the longitudinal control architecture comprises:

- [18A] communicating longitudinal motion data through a longitudinal forward speed control loop;
- [18B] communicating longitudinal motion data through a longitudinal pitch angle control loop; and
- [18C] communicating longitudinal motion data through a longitudinal pitch rate control loop.

203. As discussed in §IV.B.4.b and illustrated in annotated Figure 3 below, Gold's flight control system includes a “*longitudinal control architecture*” having 3 pitch control modules (shaded green) in the PFCS, AFCS, and VCS. As I describe below, the “*longitudinal control architecture*” includes “*a longitudinal forward speed control loop*” [8A]/[18A], “*a longitudinal pitch angle control loop*” [8B]/[18B] and “*a longitudinal pitch rate control loop*” [8C]/[18C].



Gold, Annotated Figure 3

a. “Longitudinal Forward Speed Control Loop” [8A]/[18A]

204. Gold discloses a “longitudinal forward speed control loop” [8A]/[18A]. VCS 25 of Gold’s flight control system 21 “contains control channel modules for providing **pitch axis** and roll axis velocity error signals to the AFCS.”

(DJI-1005, 3:45-46.) When operating in velocity stabilization mode, VCS pitch error signals “are fed back through PFCS proportional and integral paths to drive the error signals to zero.” (DJI-1005, 3:50-52.)

205. Gold’s Figure 4 illustrates the “functional interconnection of the VCS 25 with the PFCS 22 and the AFCS 24.” (DJI-1005, 3:54-55.) The velocity command system 25 for the pitch axis is shown in greater detail in Figure 5. In the figure below, which I have labeled Figure B, I have modified Figure 4 to incorporate the details of the pitch axis velocity control module excerpted from Figure 5 and its interconnections to the components of Figure 4.

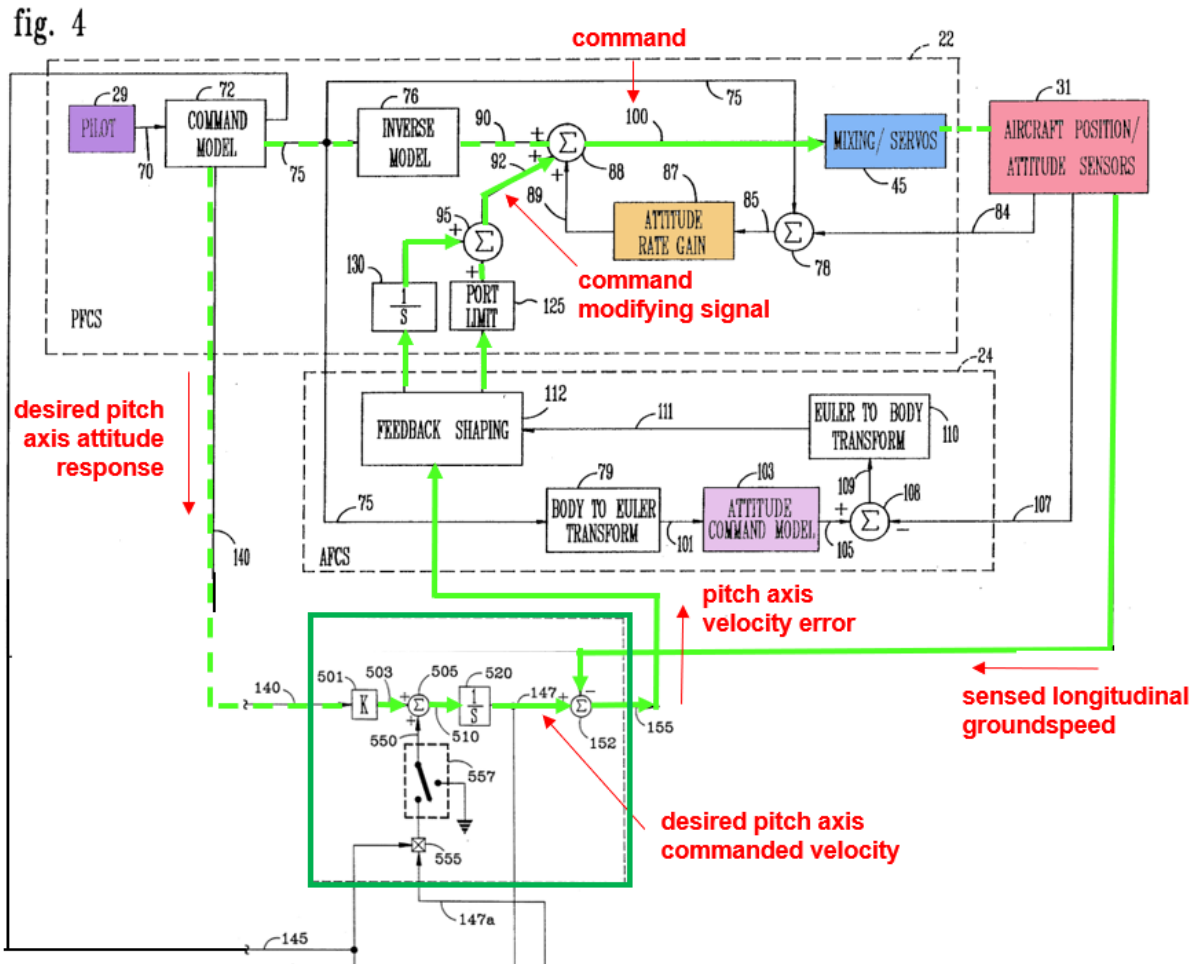


Figure B

206. In pitch axis velocity control module 500 (indicated by the green box in Figure B above), the desired pitch axis attitude response required to maintain the desired velocity in velocity stabilization mode is provided on line 140 from the command model to a gain function 501 in the VCS where it is multiplied by the gravitational constant to produce an acceleration term which is provided to summing junction 505. (DJI-1005, 5:59-64.) The summing junction also receives a

longitudinal centrifugal acceleration term on line 550 when the aircraft is operating in velocity stabilization mode. (DJI-1005, 6:38-40.) The output of summing junction 505 is provided to integrator 520, “the output of which is a desired pitch axis commanded velocity signal on the line 147.” (DJI-1005, 6:7-10.) The desired pitch axis commanded velocity signal and the longitudinal groundspeed signal 150 received from sensors 31 are provided to summing junction 152. (DJI-1005, 6:10-13.) The summing junction 152 compares the commanded velocity with the actual velocity fed back from the sensors and “provides as its output a pitch axis velocity error signal” on line 155 to the AFCS. (DJI-1005, 6:13-18.)

207. When the system is in velocity stabilization mode, feedback shaping circuitry 112 provides the pitch (longitudinal) axis velocity error signal on the integral path and “a combination of attitude feedback signals and velocity error signals to the proportional path.” (DJI-1005, 5:37-42.) The output of each is provided to a summing junction 95 in the PFCS longitudinal (pitch) controller whose output, in turn, is provided to summing junction 88. The output of summing junction 95 is a command modifying signal 92. (See DJI-1005, 4:27-28.) Summing junction 88 also receives a control command signal from inverse model 76 representing the approximate rotor command necessary to achieve the desired pitch axis rate of change. (See DJI-1005, 4:9-11.) The output of summing junction 88 is

provided on line 100 to mixing function 45 which commands displacement of mechanical servos and linkages. (DJI-1005, 3:25-29.) The sensors, in turn, provide the pitch (longitudinal) control modules, including the pitch control module of the VCS, with the aircraft's response to the rotor command signals. (See DJI-1005, 3:32-35.) This loop controls the forward component of the velocity. Accordingly, as graphically shown in Figure B above, Gold's "*longitudinal control architecture*" includes a "*longitudinal forward speed control loop*" [8A]/[18A].

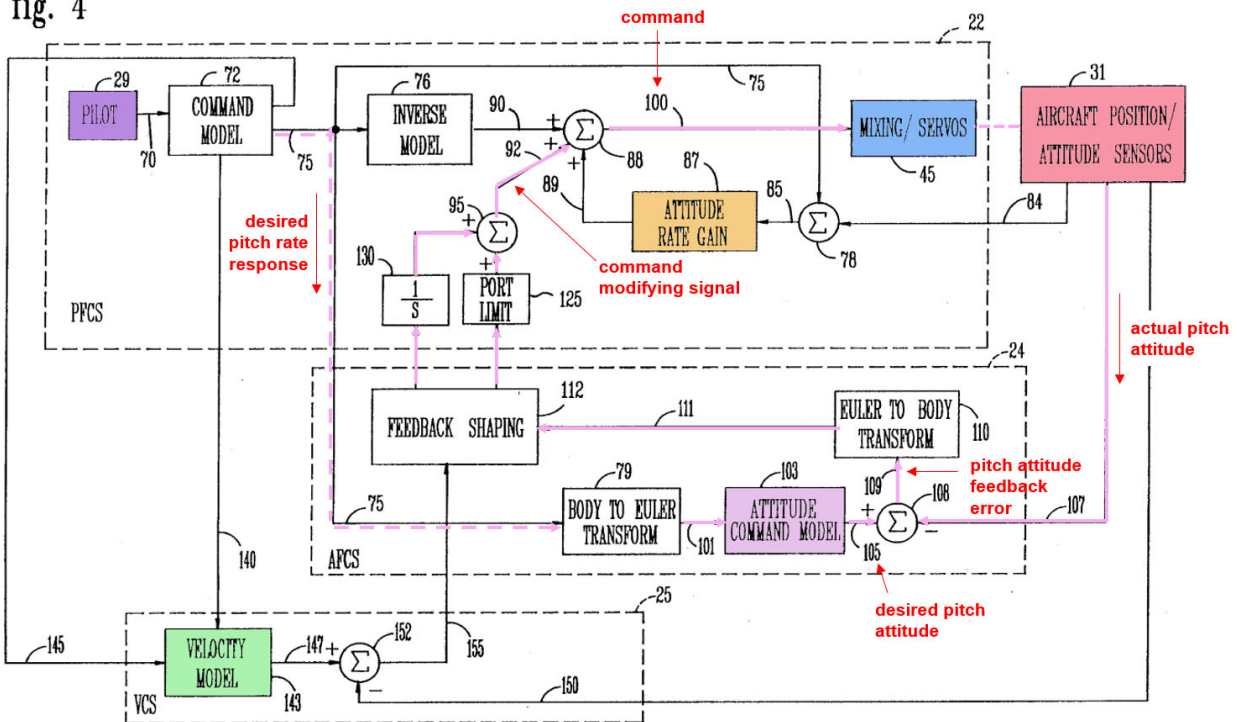
208. The pitch (longitudinal) axis velocity error determined in the VCS pitch control module is "*longitudinal motion data.*" As discussed above, the pitch axis velocity error is provided to the AFCS on line 155 and is subsequently provided to the PFCS (after shaping) through the forward speed control loop (indicated by bright green lines). Thus, Gold discloses "*communicating longitudinal motion data through a longitudinal forward speed control loop*" [18A].

b. "*Longitudinal Pitch Angle Control Loop*" [8B]/[18B]

209. Gold discloses "*a longitudinal pitch angle control loop*" [8B]/[18B]. This loop is shown below in an annotated version of Gold Figure 4. Pitch angle is the pitch attitude. (See, e.g., DJI-1001, 4:66-67 ("a longitudinal control law for pitch angle, represented as block 607 'Long_ATT'")) When a pilot pushes or pulls

(front or back) on the sidearm controller, the sidearm controller generates pitch (longitudinal) axis command signals (DJI-1005, 4:1-3.) As shown in Figure 4 below, pitch command signals from the sidearm controller are provided to command model 72 which shapes the commands “to yield a desired rate and/or attitude response.” (DJI-1005, 4:6-7.) The desired pitch rate response is provided to the Body to Euler Transformation 79 in the pitch control module of the AFCS and to the inverse model 76 in the pitch control module of the PFCS. (DJI-1005, 4:15-17.) The transformation output is provided to AFCS attitude command model 103 which includes “an integral function which converts the desired rate response to a desired pitch attitude signal on a line 105.” (DJI-1005, 4:50-54.) This desired pitch attitude signal is provided to summing junction 108 which also receives a pitch attitude signal fed back on line 107 from sensors 31. (DJI-1005, 4:54-58.) The output of the summing junction is the pitch attitude feedback error signal which is provided to Euler to Body Transform 110. This block transforms the pitch attitude feedback error signal into aircraft body axes. (DJI-1005, 4:58-63.)

fig. 4



Gold, Annotated Figure 4

210. The pitch attitude feedback error signal is applied to feedback shaping circuitry 112 in the pitch control module of the AFCS and “thereafter via a proportional path containing a gain function 125 to the summing junction 95” in the pitch control module of the PFCS. (DJI-1005, 5:1-4.) The feedback shaping signal is also applied to summing junction 95 via an integral path. (DJI-1005, 5:4-6.) Upon activation of the velocity stabilization mode, “the feedback shaping circuitry replaces the attitude feedback signals with the velocity error signals for the integral path and provides a combination of attitude feedback signals and velocity error signals to the proportional path.” (DJI-1005, 5:37-42.) The output of

summing junction 95 is the pitch command modifying signal on line 92 which “modifies the rotor command signal to achieve the pilot commanded pitch attitude.” (DJI-1005, 4:36-38.) Summing junction 88 receives this command modifying signal and a control command from inverse model 76 representing the approximate rotor command signal necessary to achieve the desired response. (See DJI-1005, 4:9-11.) The output of summing junction 88 is provided on line 100 to mixing function 45 which commands displacement of mechanical servos and linkages. (DJI-1005, 3:25-29.) The sensors, in turn, sense the response to these commands—creating a feedback loop. As shown in annotated Figure 4 above, Gold’s “*longitudinal control architecture*” includes a “*longitudinal pitch angle control loop*” [8B]/[18B].

211. The pitch (longitudinal) attitude feedback error signal is also “*longitudinal motion data*.” The pitch attitude feedback error signal is communicated from the pitch control module of the AFCS to the pitch control modules of the PFCS through the pitch angle control loop (indicated by pink lines in annotated Figure 4 above). Thus, Gold discloses “*communicating longitudinal motion data through a longitudinal pitch angle control loop*” [18B].

c. “*Longitudinal Pitch Rate Control Loop*” [8C]/[18C].

212. Gold discloses “*a longitudinal pitch rate control loop*” [8C]/[18C].

This loop is shown below on an annotated version of Gold Figure 4. As discussed above, pitch (longitudinal) command signals from the sidearm controller are provided to command model 72 which shapes the commands “to yield a desired rate and/or attitude response.” (DJI-1005, 4:6-7.) The desired rate response is provided to inverse model 76 of the pitch control module in the PFCS which “provides a command signal on a line 90 which represents the approximate rotor command necessary to achieve the desired pitch axis rate of change of the aircraft for each pilot commanded maneuver.” (DJI-1005, 4:10-13.)

fig. 4

The diagram illustrates a flight control system architecture. It includes a Pilot Command System (PCS) with a Pilot (29) and a Command Model (72). The PCS outputs a desired pitch rate response (75) to the Aircraft Position/Attitude Sensors (31). The sensors provide actual pitch rate (84) and aircraft position/attitude data (31). The system also includes a Feedback Shaping (112) block, a Velocity Model (143), and various control loops (75, 76, 79, 103, 108, 109, 111, 125, 130, 140, 145, 150, 152, 155, 158, 160, 165, 170, 175, 180, 185, 190, 195, 200, 205, 210, 215, 220, 225, 230, 235, 240, 245, 250, 255, 260, 265, 270, 275, 280, 285, 290, 295, 300, 305, 310, 315, 320, 325, 330, 335, 340, 345, 350, 355, 360, 365, 370, 375, 380, 385, 390, 395, 400, 405, 410, 415, 420, 425, 430, 435, 440, 445, 450, 455, 460, 465, 470, 475, 480, 485, 490, 495, 500, 505, 510, 515, 520, 525, 530, 535, 540, 545, 550, 555, 560, 565, 570, 575, 580, 585, 590, 595, 600, 605, 610, 615, 620, 625, 630, 635, 640, 645, 650, 655, 660, 665, 670, 675, 680, 685, 690, 695, 700, 705, 710, 715, 720, 725, 730, 735, 740, 745, 750, 755, 760, 765, 770, 775, 780, 785, 790, 795, 800, 805, 810, 815, 820, 825, 830, 835, 840, 845, 850, 855, 860, 865, 870, 875, 880, 885, 890, 895, 900, 905, 910, 915, 920, 925, 930, 935, 940, 945, 950, 955, 960, 965, 970, 975, 980, 985, 990, 995). The system is designed to control the aircraft's pitch rate and position based on pilot commands and sensor feedback.

Gold, Annotated Figure 4

213. The desired rate response on line 75 is also provided to summing junction 78 which “compares the desired rate response on line 75 with the aircraft’s actual pitch rate, received (from sensors 31, through lines 32 and trunk 33) as a sensed pitch rate signal on line 84.” (DJI-1005, 4:17-21.) The output of summing junction 78 “is a pitch rate error signal on a line 85.” (DJI-1005, 4:21-22.) The pitch rate error is applied to a proportional gain function 87 (to reduce the error) and the output is provided to summing junction 88. (DJI-1005, 4:22-25.) Summing junction 88 also receives the control command from inverse model 76. (See, e.g., DJI-1005, 4:25-27.) The output of summing junction 88 is provided on

line 100 to mixing function 45 which commands displacement of mechanical servos and linkages. (DJI-1005, 3:25-29.) The sensors, in turn, sense the response to these commands—creating a feedback loop. As shown in annotated Figure 4 above, Gold’s “*longitudinal control architecture*” includes a “*longitudinal pitch rate control loop*” [8C]/[18C].

214. The pitch rate error is also “*longitudinal motion data*.” The pitch rate error signal is provided through the pitch rate control loop (indicated by orange lines in annotated Figure 4 above) to gain function 87 on a line 85 whose output is provided to summing junction 88, as discussed above. (DJI-1005, 4:21-22.) Thus, Gold discloses “*communicating longitudinal motion data through a longitudinal pitch rate control loop*” [18C].

5. “*Longitudinal Controller*” (claims 9 and 19)

215. Claims 9 and 19, reproduced below, are directed to a “*longitudinal controller*.” Gold discloses the subject matter of these claims.

9. The aircraft of claim 8, the longitudinal control architecture further comprising:

[9A] a longitudinal controller carried by the aircraft, the longitudinal controller being manipulated by a pilot controlling the aircraft,

[9B] the longitudinal controller creating a longitudinal command in data communication with the longitudinal forward speed control

loop, the longitudinal pitch angle control loop, and the longitudinal pitch rate control loop.

19. The method of claim 19, the longitudinal control architecture further comprising:

controlling the longitudinal direction of motion with a longitudinal controller manipulated by a pilot controlling the aircraft, the longitudinal controller being operably associated with the longitudinal control architecture.

216. Gold's PFCS, AFCS, and VCS receive command signals from sidearm controller 29, as shown in Figure 3. (DJI-1005, 3:10-12.) Specifically, "pitch axis command signals are generated by the pilot's pushing and pulling (front or back) of the sidearm controller." (DJI-1005, 3:64-4:4.) Because it controls pitch axis (longitudinal) movement, Gold's sidearm controller 29 is a "*a longitudinal controller carried by the aircraft, the longitudinal controller being manipulated by a pilot controlling the aircraft*" [9A]. (See DJI-1001, 4:22-30 (recognizing that the same physical input device can act as yaw controller, lateral controller, longitudinal controller, and vertical controller).)

217. The PFCS and AFCS of the flight control system each contain control modules for controlling the pitch (longitudinal) axis of the aircraft. (DJI-1005, 3:17-18.) As discussed in §IV.D.4, pitch command signals from the sidearm

controller are provided to command model 72 of the PFCS and AFCS which shape the commands “to yield a desired rate and/or attitude response.” (DJI-1005, 4:6-7.) The shaped pitch command is provided to each of “*the longitudinal forward speed control loop, the longitudinal pitch angle control loop, and the longitudinal pitch rate control loop*” as I discussed in §IV.D.4. Thus, Gold discloses “*the longitudinal controller creating a longitudinal command in data communication with the longitudinal forward speed control loop, the longitudinal pitch angle control loop, and the longitudinal pitch rate control loop*” [9B].

218. As discussed above, pitch command signals from the sidearm controller are provided to command model 72 of the PFCS and AFCS. The pitch control module in the PFCS and AFCS “provide[s] rotor command signals” to “a rotor mixing function 45 which commands displacement of mechanical servos 46 and linkages 47 to control the tip path plane of a main rotor 50.” (DJI-1005, 3:25-29.) As I discussed in §III.A.1, 4, tilting the tip path plane of the main rotor forward or aft induces longitudinal movement. Thus, Gold discloses “*controlling the longitudinal direction of motion with a longitudinal controller manipulated by a pilot controlling the aircraft, the longitudinal controller being operably associated with the longitudinal control architecture*” [19].

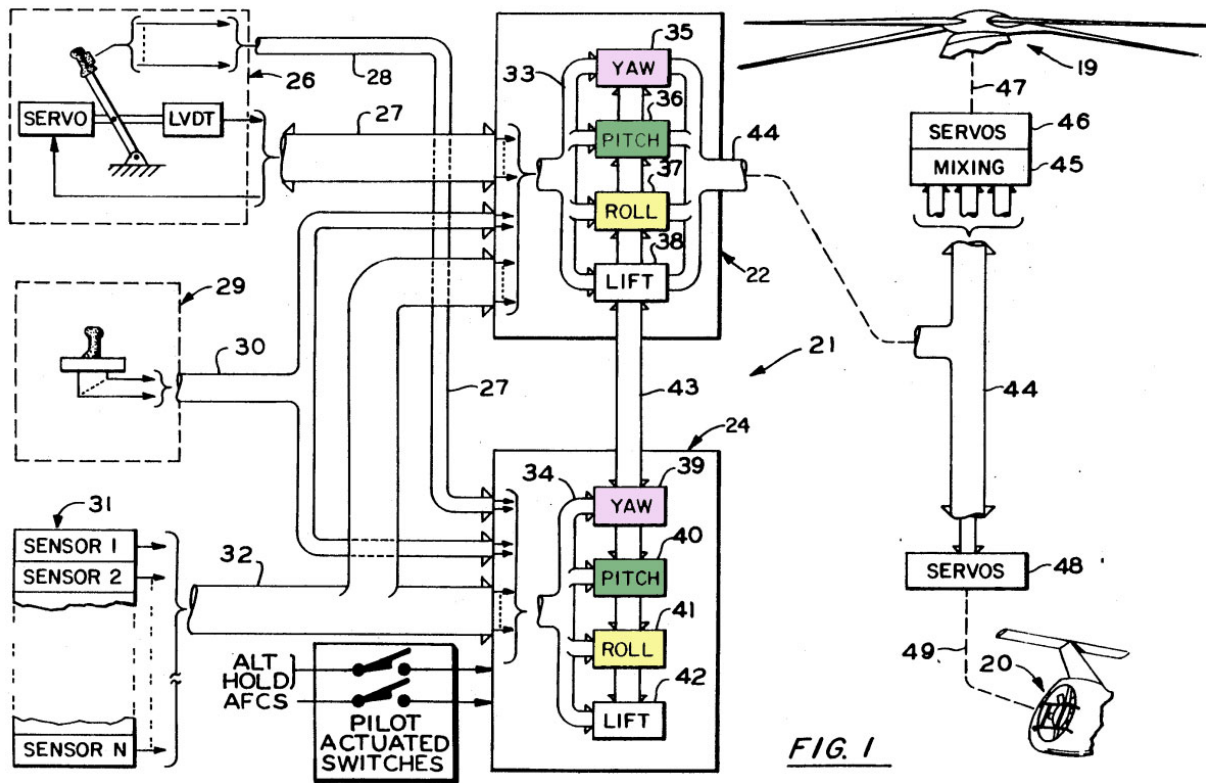
V. GROUND 2: The combination of Gold, Shue, Gold-Paper, and Skonieczny renders claims 3-4 and 13-14 obvious.

A. Overview of Combination

1. Skonieczny

219. U.S. Patent 5,238,203 to Skonieczny, et al. (“Skonieczny”) was filed on August 28, 1991, and issued on August 24, 1993, almost 18 years before the earliest possible priority date of the ’082 patent. Skonieczny “relates to flight control systems for rotary wing aircraft, and more particularly to such flight control systems which provide automatic turn coordination control.” (DJI-1006, 1:10-13.) Skonieczny explains that “[c]ontrol of yaw axis commands to the tail rotor is critical to this type of maneuver.” (DJI-1006, 1:21-22.)

220. Like Gold, Skonieczny describes “a model following control system which shapes the pilot’s sidearm controller and displacement stick commands through an ‘inverse vehicle model’ to produce the desired aircraft response.” (DJI-1006, 2:62-67.) Skonieczny’s system, illustrated in annotated Figure 1 below, includes Primary Flight Control System (PFCS) 22 and Automatic Flight Control System (AFCS) 24. Each of the PFCS and AFCS contains “control channel logic for controlling the yaw [shaded pink], pitch [shaded green], roll [shaded yellow] and lift axes of the aircraft.” (DJI-1006, 3:12-14.)

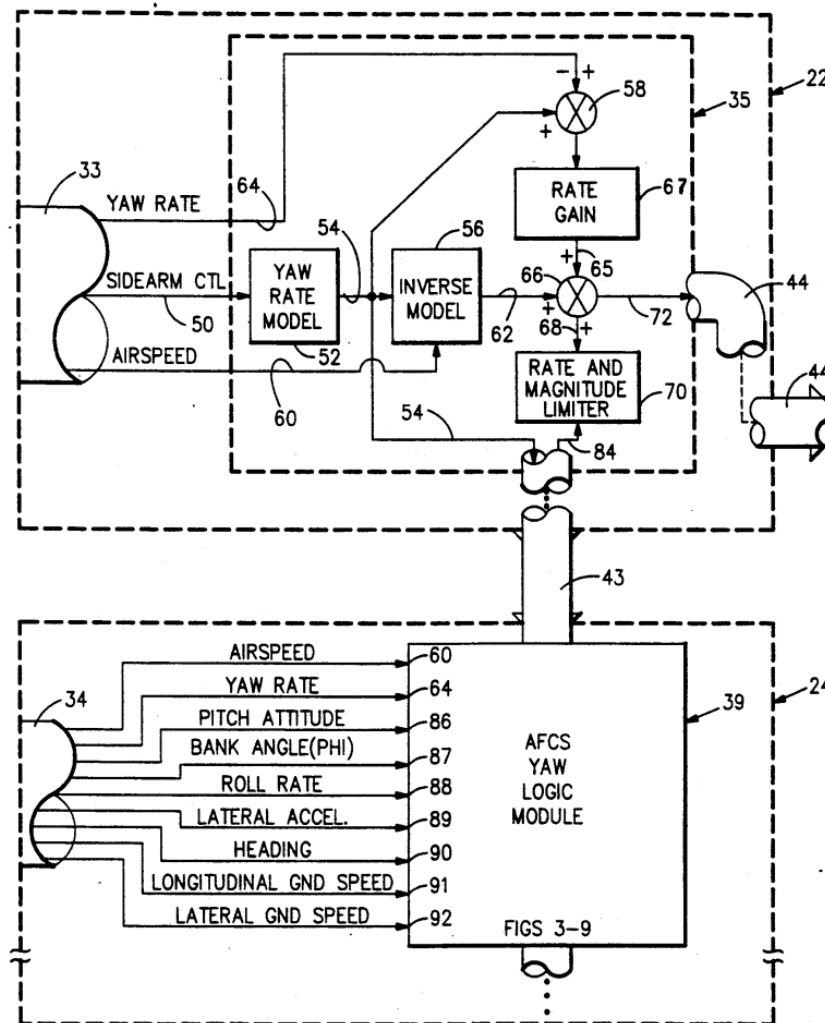


Skonieczny, Annotated Figure 1

221. PFCS 22 “receives displacement command output signals from a displacement collective stick 26” and AFCS 24 “receives the collective stick discrete output signals.” (DJI-1006, 3:1-4.) Each “receive[s] the force output command signals of a four axis sidearm controller 29, on lines 30, and the aircraft’s sensed parameter signals from sensors 31, on lines 32.” (DJI-1006, 3:4-8.) The PFCS and AFCS “provide rotor command signals on output lines 44 to main rotor mixing function 45 which commands displacement of mechanical servos 46 and linkages 47 to control the tip path plane of the main rotor 19” and

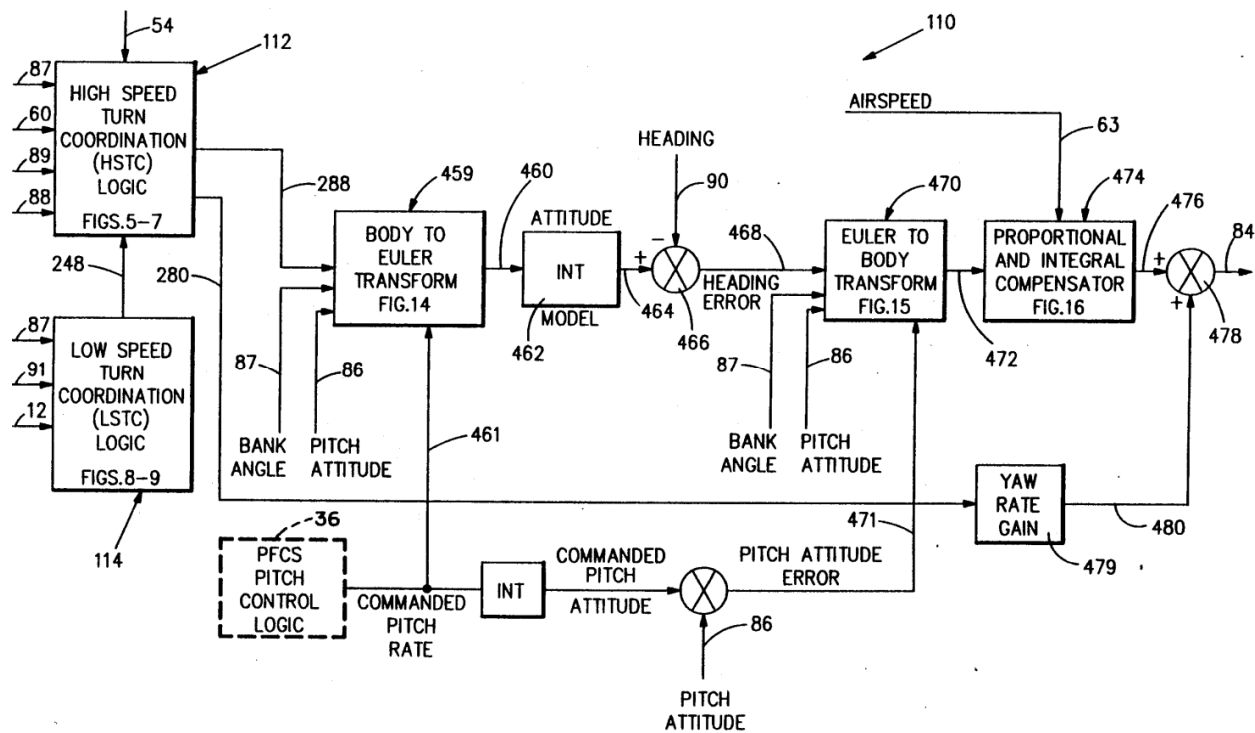
“to the helicopter’s tail rotor servos 48 which control the thrust of the tail rotor 20 through linkages 49.” (DJI-1006, 3:20-28.) The sensed signals from sensors 31 “provide the PFCS and AFCS with the aircraft’s angular rate and attitude response to the rotor command signals.” (DJI-1006, 3:28-30.)

222. The functional interconnection of Skonieczny’s PFCS 22 and AFCS 24 yaw logic modules 35 and 39 are shown in Skonieczny Figure 2 below.



Skonieczny, Figure 2

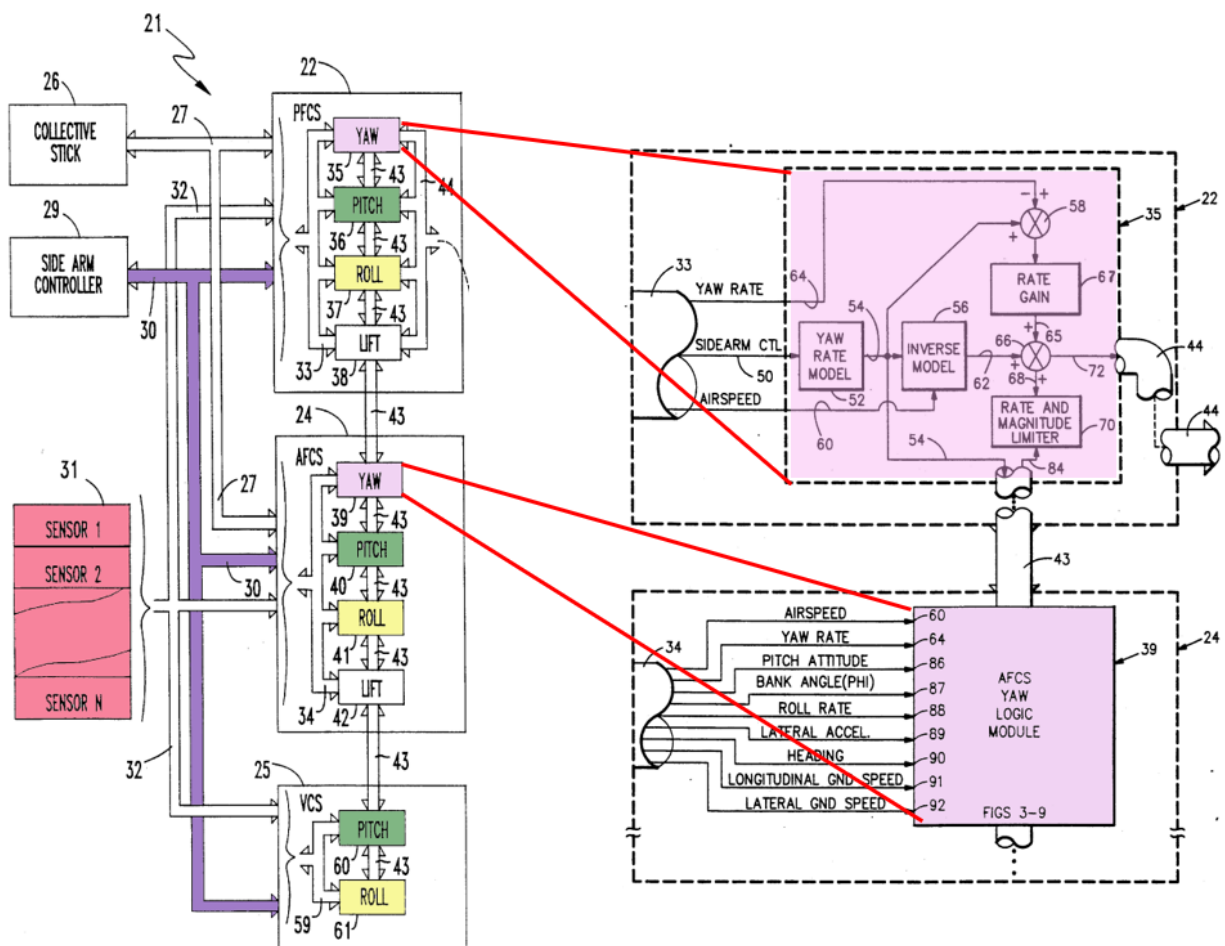
223. AFCS yaw logic 110, executable in a microprocessor of the AFCS, is illustrated in Skonieczny Figure 4 below. Yaw logic 110 includes both High Speed Turn Coordination (HSTC) logic 112 and Low Speed Turn Coordination (LSTC) logic 114. (DJI-1006, 5:16-21.) HSTC logic 112 “includes the logic for conditioning pilot commanded yaw inputs via the sidearm controller at speeds above 60 knots.” (DJI-1006, 5:24-26.) In contrast, LSTC logic 114 “is operational only between 0 and 80 knots ; providing full authority from 25 to 60 knots, and limited authority between 0 and 25 knots, and 60 to 80 knots.” (DJI-1006, 9:55-58.)



Skonieczny, Figure 4

2. Motivation to Combine Gold, Shue, Gold-Paper, and Skonieczny

224. A POSITA would have been motivated to combine Skonieczny's yaw module teachings with the flight control system of the combination of Gold, Shue, and Gold-Paper, as illustrated in the figure below, for various reasons.



Excerpt from Gold, Annotated Figure 3; Skonieczny, Annotated Figure 2

225. First, Gold explicitly incorporates Skonieczny by reference and for this reason alone, a POSITA would have been motivated to combine Gold with Skonieczny:

- “A more detailed description of the model following algorithms of the AFCS, and AFCS architecture, is given in commonly owned **U.S. Pat. No. 5,238,203**, entitled “High Speed Turn Coordination For A Rotary Wing Aircraft”, **the disclosure of which is incorporated herein by reference.**” (DJI-1005, 4:38-43.)
- “The operation of both Transform functions 79, 110 are described in greater detail in the aforementioned commonly owned **U.S. Pat. No. 5,238,203**, **the disclosure of which is incorporated herein by reference.**” (DJI-1005, 4:63-37.)

226. Second, Gold expressly suggests the combination. Gold states that switches 557 and 567 of Figure 5 “open[] in response to the aircraft operating in the **automatic turn coordination** mode.” (DJI-1005, 6:46-48.) However, Gold does not provide discussion of automatic turn coordination logic. Based on this suggestion, a POSITA would have been motivated to combine Gold with a reference disclosing “automatic turn coordination.” Skonieczny is directed to automatic turn coordination and is incorporated by reference as discussed above. (See DJI-1006, 1:10-13; 5:19-21 (“The logic comprises both High Speed Turn

Coordination (HSTC) logic 112 and Low Speed Turn Coordination (LSTC) logic 114”); Title (“High speed turn coordination for rotary wing aircraft”).) Skonieczny, Gold, Shue, and Gold-Paper are in the same field of endeavor as the ’082 patent—control systems for aircraft—and are therefore analogous art.

227. Third, Gold relates to “a velocity command system” allowing “a pilot to yaw the aircraft during operation in a velocity stabilization mode without changing the flight path of the aircraft with respect to the inertial reference.” (DJI-1005, 1:9-14.) Gold focuses its discussion on pitch and roll control modules. However, Gold includes limited discussion of its yaw control modules. Therefore, a POSITA would have been motivated to search for references related to yaw control and would have been led to Skonieczny. As discussed above, Gold explicitly directs a reader to Skonieczny and Skonieczny’s inventor list includes the same inventors as Gold (Gold, Fogler, and Dryfoos).

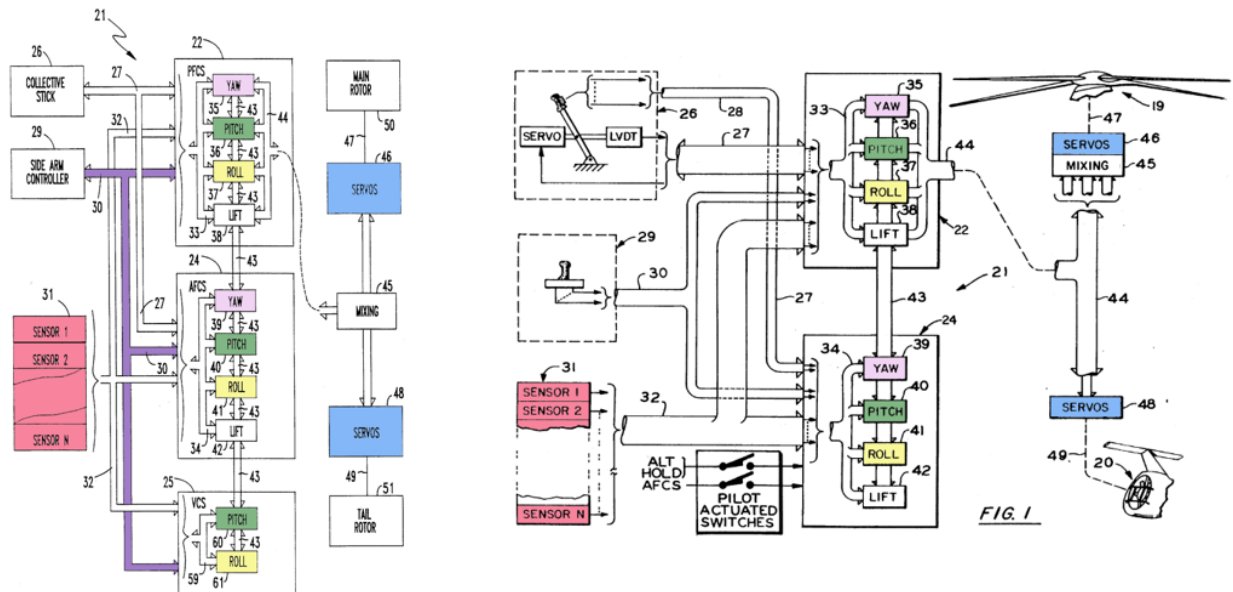
228. Fourth, the combination is merely the simple substitution of one known element (Gold’s yaw modules 35 and 39) for another (Skonieczny’s yaw modules 35 and 39) to yield predictable results. A POSITA would have had a reasonable expectation of success in the combination and the results of the combination would have been predictable because both Gold and Skonieczny use the same basic architecture for the PFCS and AFCS. Gold describes a model

following control system having a PFCS and AFCS each with “control modules for controlling the yaw, pitch, roll and lift axes of the aircraft.” (DJI-1005, 3:17-20.)

Skonieczny discloses an identical model following architecture for the PFCS and AFCS and even uses the same reference numbers for components, as illustrated

below in the side-by-side comparison of Gold’s Figure 3 and Skonieczny’s Figure

1.



Gold, Annotated Figure 3 (left); Skonieczny, Annotated Figure 1 (right)

B. “Directional Control Architecture” Claims (3 and 13)

229. Claims 3 and 13, reproduced below, are directed to a “*directional control architecture.*” The combination of Gold, Shue, Gold-Paper, and Skonieczny renders these claims obvious.

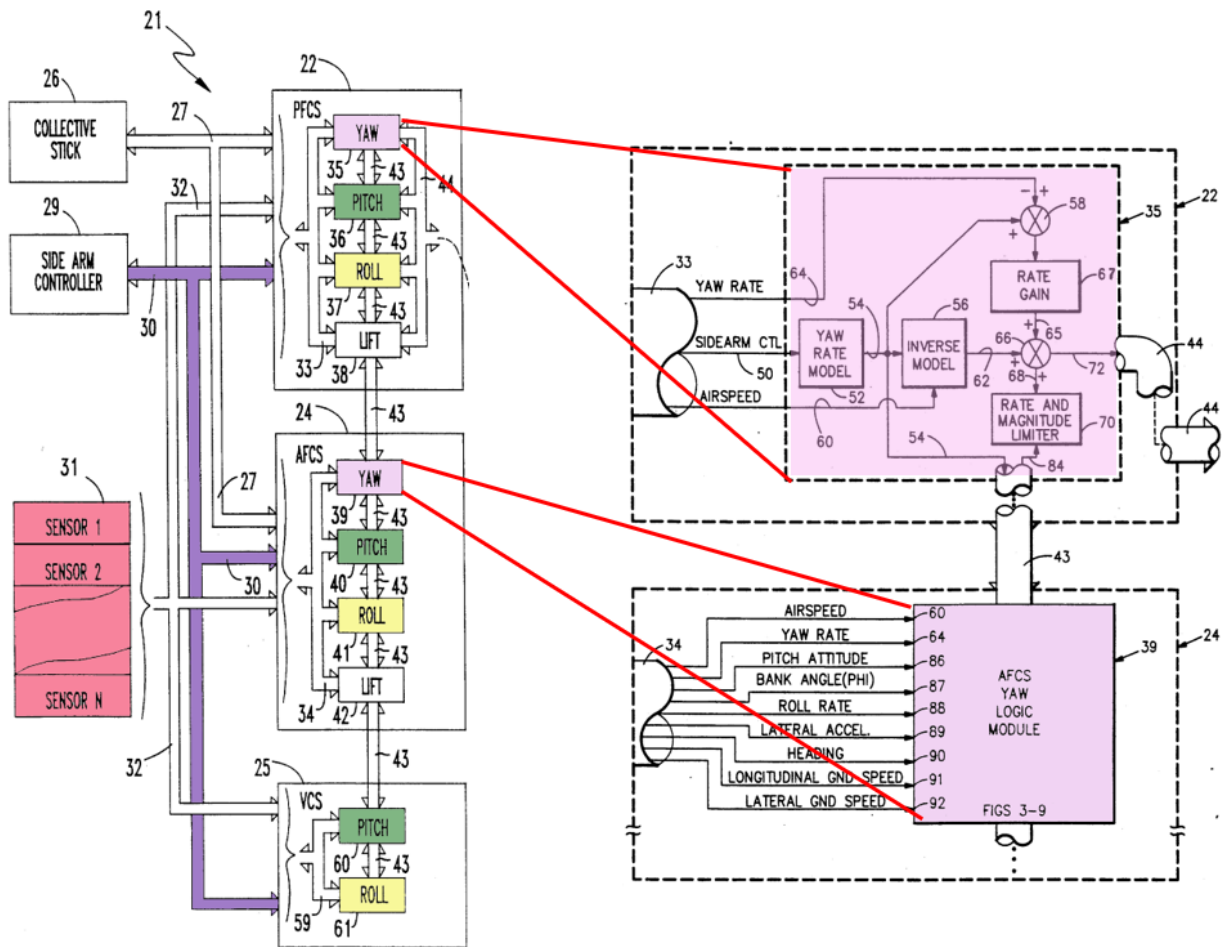
3. The aircraft of claim 2, the directional control architecture comprising:

- [3A] a directional heading control loop;
- [3B] a directional turn coordination control loop; and
- [3C] a directional yaw rate control loop.

13. The method of claim 12, wherein the commanding of the flat yawing turns with the directional control architecture comprises:

- [13A] communicating data through a directional heading control loop;
- [13B] communicating data through a directional turn coordination control loop; and
- [13C] communicating data through a directional yaw rate control loop.

230. Yaw control module 35 of PFCS and yaw control module 39 of the AFCS, illustrated in the figures below, in the combination of Gold, Shue, Gold-Paper, and Skonieczny are collectively part of the “*directional control architecture*” of the flight control system, as I discussed in my analysis of claims 2 and 12.



Excerpt from Gold, Annotated Figure 3; Skonieczny, Annotated Figure 2

231. As I describe below, the “*directional control architecture*” includes “a *directional heading control loop*” [3A]/[13A], “a *directional turn coordination control loop*” [3B]/[13B], and “a *directional yaw rate control loop*” [3C]/[13C].

1. “*Directional Heading Control Loop*” [3A]/[13A]

232. The combination of Gold, Shue, Gold-Paper, and Skonieczny discloses “a *directional heading control loop*” [3A]/[13A]. Skonieczny Figure 2

illustrates “the functional interconnection of the PFCS 22 and AFCS 22 yaw logic modules 35 and 39.” (DJI-1006, 3:32-34.) Skonieczny Figure 4 “is a block diagram of the AFCS yaw logic.” (DJI-1006, 5:16-17.) In the figure below, which I have labeled Figure C, I have replaced the AFCS yaw module 39 from Skonieczny Figure 2 with the AFCS logic 110 of Skonieczny Figure 4. In this Figure, I have also added the servos and sensors from Skonieczny Figure 1 to obtain a unified representation of the control system.

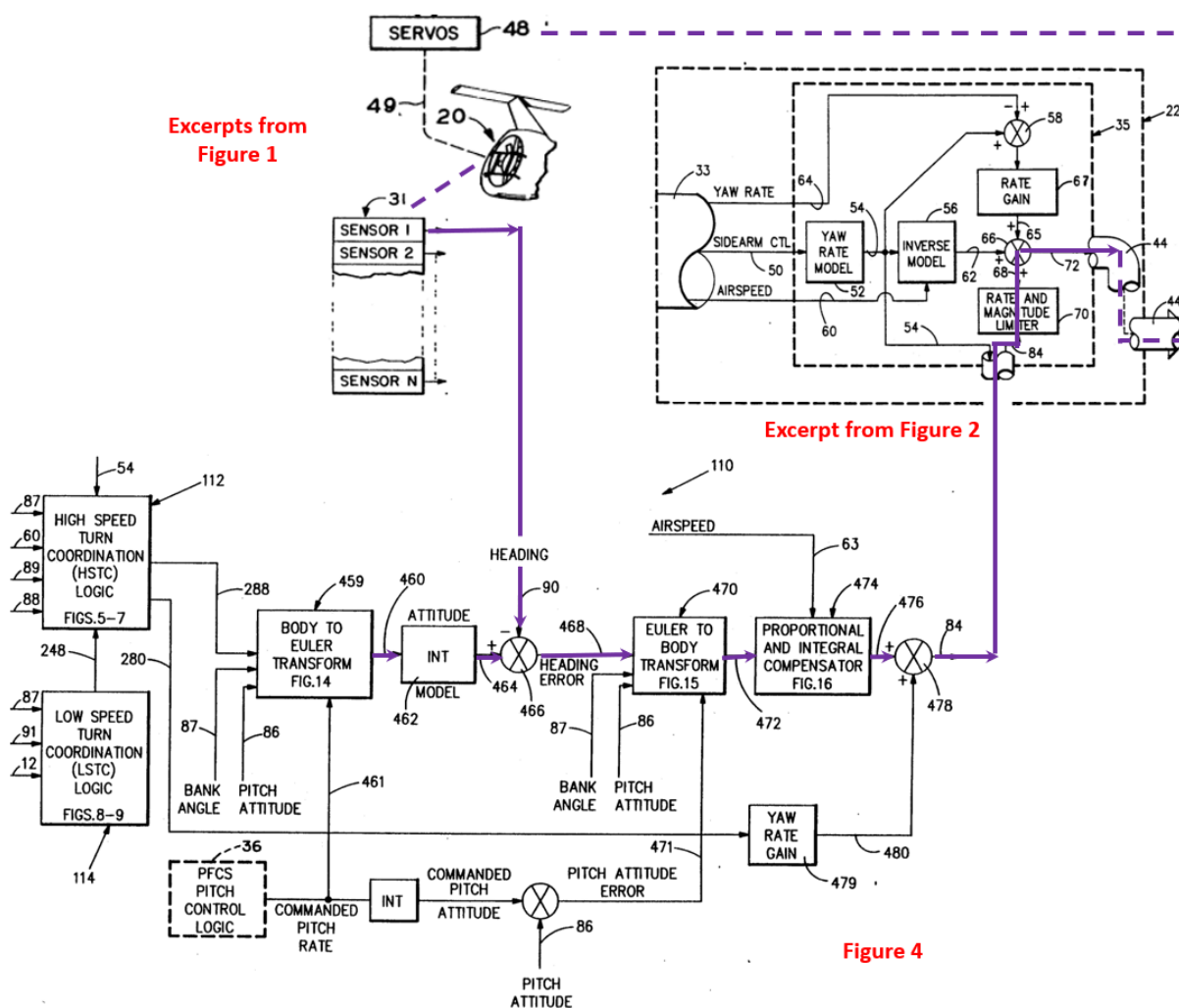
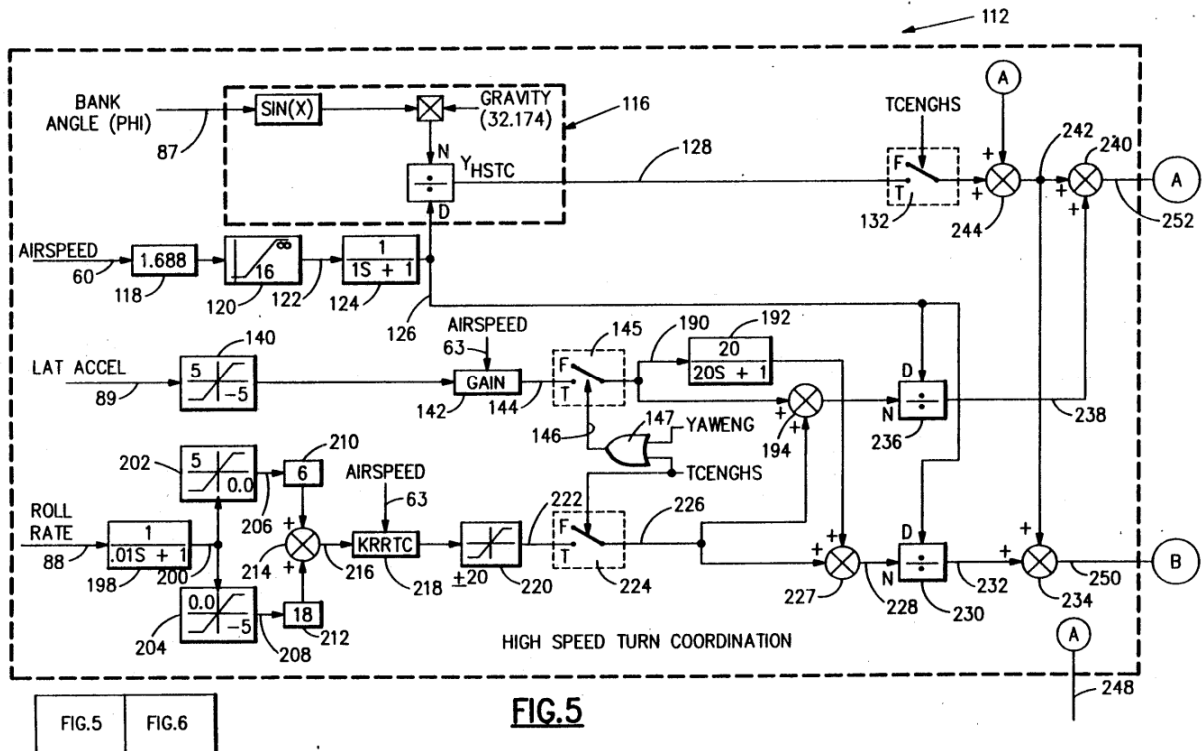


Figure C

233. Both PFCS yaw module 35 and AFCS yaw module 39 are active when a yaw maneuver is initiated, regardless of whether HSTC or LSTC is engaged. For example, if high speed turn coordination is not engaged, switches determine what sensor data is used for determination of the desired yaw rate commands output by HSTC logic. (*See, e.g.*, DJI-1006, Figure 5 below (illustrating the TCENGHS signal that activates switches in HSTC logic).) As shown in Figure

5, airspeed is communicated through HSTC logic and used in the determination of the command yaw rate, regardless of whether high speed turn coordination is engaged. (See, e.g., DJI-1006, Figure 5.)



Skonieczny, Figure 5

234. HSTC logic 112 in AFCS yaw logic 110 (illustrated in Skonieczny Figure 4) receives a commanded yaw rate from the PFCS on line 54 and data from sensors 31 including bank angle 87, airspeed 60, lateral acceleration 89, and roll rate 88. (See, e.g., DJI-1006, 5:29-31; 4:44-58.) After processing, HSTC logic 112 outputs two different yaw rate command signals on lines 280, 288. (DJI-1006, 8:38-40.)

235. After being transformed from Body to Euler angles in block 459, the yaw rate command is input to an aircraft attitude model 462 which “integrates the desired yaw rate signal on the line 460 over time, providing a signal indicative of **desired aircraft heading** on a line 464 to a summing function 466.” (DJI-1006, 12:36-42.) Summing function 466 also receives “the **actual aircraft heading signal** on the line 90” from sensors 31 and “provides a **heading error signal** on a line 468.” (DJI-1006, 12:42-45.) After further processing, a yaw command modifying signal is provided on line 84 by the yaw module of the AFCS to the yaw module of the PFCS. “The magnitude and rate of change of the yaw command modifying signal from the AFCS is a function of the aircraft heading error.” (DJI-1006, 4:22-24.)

236. Summing junction 66 of the yaw module of the PFCS (shown in Figure 2) receives the desired yaw rate command and the yaw command modifying signal 68. (DJI-1006, 4:10-13.) The resulting command signal, provided on line 72, is sent through trunk lines 44 to the tail rotor servos (48, Figure 1). (DJI-1006, 4:18-21.) Sensors, in turn, measure the response to these commands and provide the sensed heading on line 90—creating a feedback loop. (DJI-1006, 4:46-53.) The aircraft heading error, described above, “is the second of two feedback loops around the tail rotor command signal.” (DJI-1006, 4:24-26.) Controlling the yaw

rate is a way of controlling the directional heading. Accordingly, as shown in my Figure C above, the “*directional control architecture*” of the combination of Gold and Skonieczny includes “*a directional heading control loop*” [3A]/[13A].

237. The heading error is one form of “*data*” communicated through and/or used by the “*directional heading control loop*” (illustrated by the purple lines in my Figure C above). As discussed above, the heading error is communicated through the “*directional heading control loop*.” The yaw control modules, including AFCS yaw logic 110, are active when a yaw maneuver is initiated by a pilot (including during a flat turn or during a banked turn). Therefore, the combination of Gold, Shue, Gold-Paper, and Skonieczny discloses “*communicating data [e.g., heading error] through a directional heading control loop*” [13A].

2. “*Directional Turn Coordination Control Loop*” [3B]/[13B]

238. The combination of Gold, Shue, Gold-Paper, and Skonieczny discloses “*a directional turn coordination control loop*” [3B]/[13B]. In the figure below, which I have labeled Figure D, I have modified Skonieczny Figure 2 to replace the AFCS with the detailed AFCS logic of Skonieczny Figure 4. The AFCS yaw logic includes both High Speed Turn Coordination (HSTC) logic 112 and Low Speed Turn Coordination (LSTC) logic 114 (which I collectively refer to

as a “turn coordination” logic). (*See, e.g.*, DJI-1006, 5:29-31; 4:44-58.) As shown in this figure, HSTC logic 112 receives the commanded yaw rate signal on line 54 from the PFCS and the bank angle 87, actual airspeed 60, lateral acceleration 89, and roll rate 88 from the sensors. The HSTC logic receives this data when a yaw maneuver is initiated as I discussed above in §V.B.1 (even if high speed or low speed turn coordination is not engaged). (*See, e.g.*, DJI-1006, 5:29-31; 4:44-58.) The operation of the HSTC logic is described in further detail by Skonieczny with reference to Figures 5 and 6. (*See* DJI-1006, 5:29-8:60.) The LSTC logic receives bank angle 87, longitudinal ground speed 91 and lateral ground speed 92 from sensors 31. (*See also*, DJI-1006, 8:63-65, 4:44-53.) The operation of the LSTC logic is described in further detail by Skonieczny with reference to Figure 8. (*See also*, DJI-1006, 8:63-10:17.)

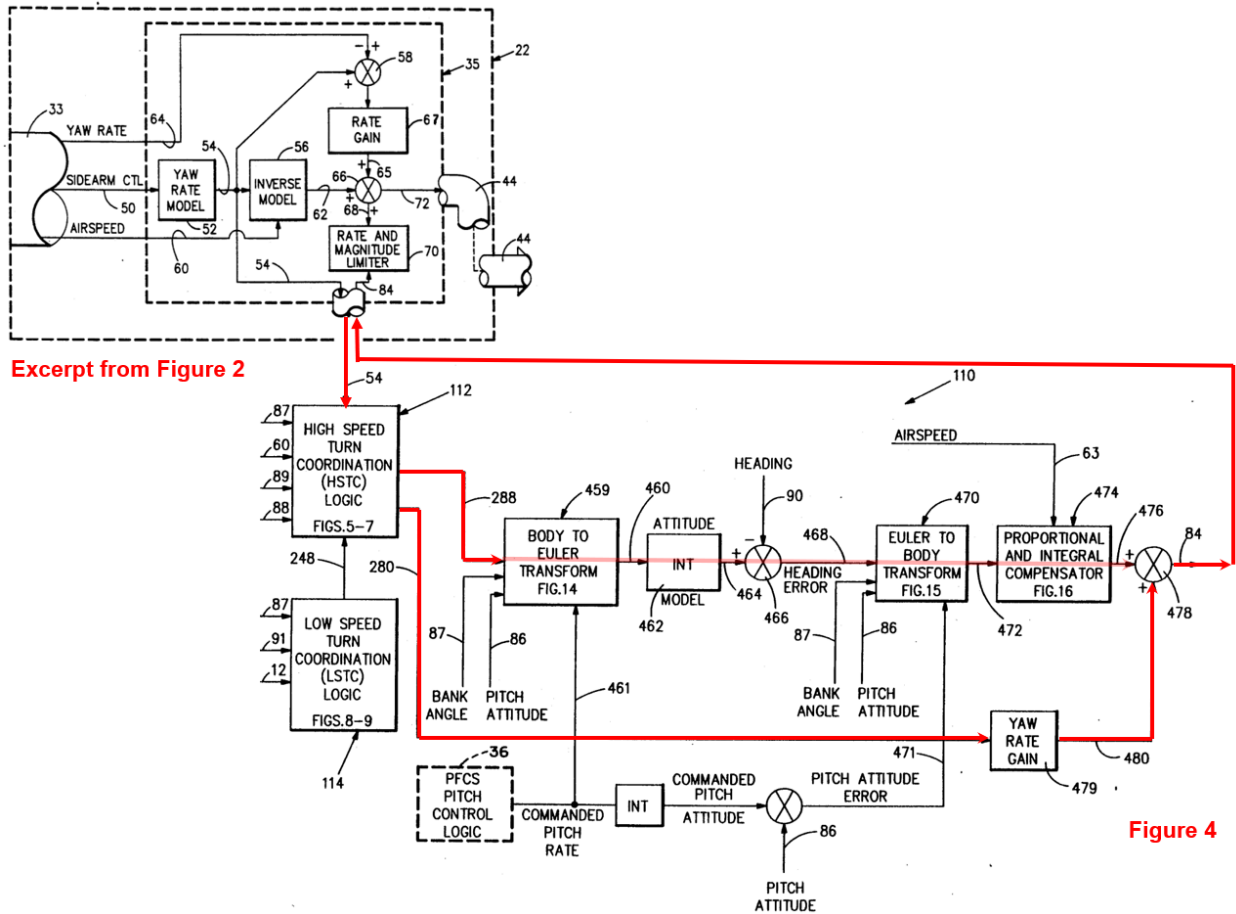


Figure D

239. The HSTC logic outputs two yaw rate command signals on lines 280 and 288, as I mentioned previously. After undergoing a Body to Euler transformation in 459, yaw rate command signal 460 is provided to attitude model 462 which “integrates the desired yaw rate signal on the line 460 over time, providing a signal indicative of desired aircraft heading on a line 464 to a summing function 466.” (DJI-1006, 12:36-42.) Summing function 466 also receives “the actual aircraft heading signal” from sensors 31 and “provides a heading error

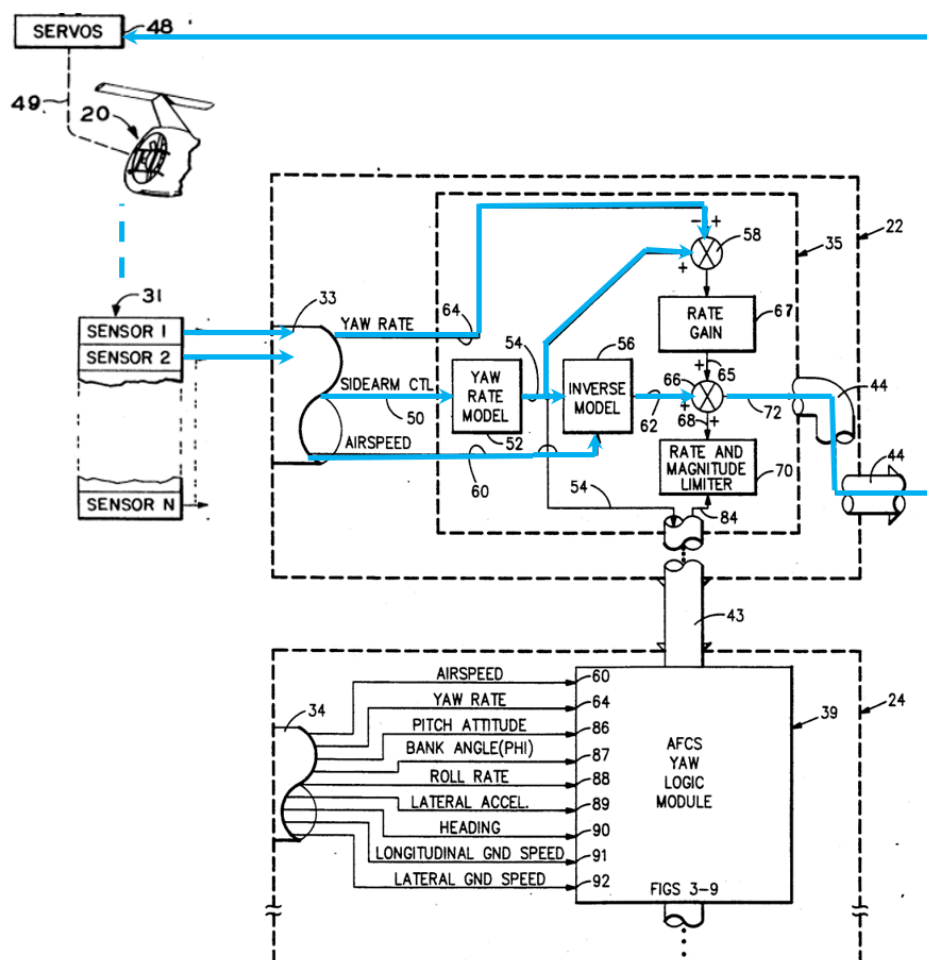
signal on a line 468.” (DJI-1006, 12:42-45.) After further processing, a yaw command modifying signal 84 is provided by the yaw module of the AFCS to the yaw module of the PFCS. Therefore, the “*directional control architecture*” of the combination of Gold, Shue, Gold-Paper, and Skonieczny includes “*a directional turn coordination loop*” [3B]/[13B].

240. As shown in my Figure D above, various forms of data are communicated through the turn coordination logic (HSTC and LSTC) including sensor data, yaw rate commands, and error data. This data is communicated through AFCS yaw logic 110, as discussed above, when a yaw maneuver is initiated by a pilot (including during a flat turn or during a banked turn). Thus, the combination of Gold, Shue, Gold-Paper, and Skonieczny discloses “*communicating data through a directional turn coordination control loop*” [13B].

3. “*Directional Yaw Rate Control Loop*” [3C]/[13C]

241. The combination of Gold, Shue, Gold-Paper, and Skonieczny discloses “*a directional yaw rate control loop*” [3C]/[13C]. Functional interconnections of the PFCS 22 and AFCS 24 yaw logic modules 35 and 39 are illustrated below in an annotated version of Skonieczny Figure 2 with the sensors and servos from Figure 1 added. Yaw rate model circuitry 52 in the PFCS yaw logic module 35 “receives a yaw axis command signal” from sidearm controller on

line 50 when a yaw maneuver is initiated by the pilot. (DJI-1006, 3:35-43.) Yaw rate model circuitry provides a commanded yaw rate signal on line 54 “indicative of the desired rate of change for the aircraft attitude about the yaw axis.” (DJI-1006, 3:41-47.) The yaw rate signal is presented to inverse model 56 and summing junction 58. Summing junction 58 “sums the commanded yaw rate signal on line 54 (from the yaw rate model 52) with the aircraft’s actual yaw rate, received (from sensors 31, through lines 32 and trunk 33) as a sensed yaw rate signal” to provide a yaw rate error signal. (DJI-1006, 4:3-7.)



Skonieczny, Annotated Figure 2⁴ (with sensors and servos added)

⁴ Skonieczny Figure 2 includes an error that would have been understood and corrected by a POSITA. For example, Rate and Magnitude Limiter block 70 only has arrows going into the block but should depict an arrow going out line 68 to the summer 66.

242. Summing junction 66 receives the rate error signal (gain adjusted), the desired yaw rate signal from inverse model 56, and a yaw modifying signal from the AFCS. (DJI-1006, 4:10-14.) The resulting command signal, provided on line 72, is sent through trunk lines 44 to the tail rotor servos (48, Figure 1). (DJI-1006, 4:18-21.) Sensors 31, in turn, measure the response to these commands and provide sensed yaw rate and airspeed to the yaw control module of the PFCS, thereby creating a feedback loop. (DJI-1006, 4:46-53.) Therefore, the “*directional control architecture*” of the combination of Gold, Shue, Gold-Paper, and Skonieczny discloses “*a directional yaw rate control loop*” [3C]/[13C].

243. The yaw rate error signal is one form of “*data*” communicated through and used in the “*directional yaw rate control loop*.” As shown in the above annotated version of Skonieczny Figure 2, the yaw rate error, as well as other data, is communicated through the yaw rate control loop (indicated by light blue lines). Yaw module 35 is active when a yaw maneuver is initiated by a pilot (including during a flat turn or during a banked turn). Thus, the combination of Gold, Shue, Gold-Paper, and Skonieczny discloses “*communicating data through a directional yaw rate control loop*” [13C].

C. “Directional Control Latch” (claims 4 and 14)

244. Claims 4 and 14 recite subject matter directed to “*a directional control latch.*” The combination of Gold, Shue, Gold-Paper, and Skonieczny renders these claims obvious.

4. The control system of claim 3, further comprising:

[4A] a directional control latch in data communication with the directional control architecture;

[4B] wherein, as the directional controller is moved out of a detent position, the directional control latch activates a constant vector flat turn motion.

14. The method of claim 12, further comprising:

activating the constant vector flat turn with a directional control latch as the directional controller is moved out of a detent position.

245. The '082 patent specification does not discuss a “*directional control latch.*” However, it does discuss latches generally. In the discussion of Figure 9, the '082 patent explains that “[c]ontrol law **logic** 901 comprises one or more of latch 903, latch 905, and latch 907 adapted to control when a mode is turned on or off.” (DJI-1001, 7:14-16.) Thus, the '082 patent encompasses embodiments in which a latch is logic (software) turning a control mode on or off. Furthermore, all

the latches disclosed in Figure 9 are associated with the detent position of the controller manually manipulated by the pilot.

246. Gold-Paper describes response types within its velocity stabilization mode. Gold-Paper discloses control laws for the RAH-66 Comanche helicopter that “have been tailored to satisfy the requirements of ADS-33C”, an earlier version of ADS-33E discussed in DJI-1026. Response types typically include either the word “command” (e.g., translational rate command), the word “hold” (e.g., position hold), or both (e.g., yaw rate command/direction hold). (See DJI-1026, 6-10.) The term that immediately precedes the word “command” in a response type generally describes what the pilot is commanding when the pilot moves the corresponding pilot controller out of the detent position, and the term that immediately precedes the word “hold” in a response type generally describes what the aircraft should try to maintain when the corresponding pilot’s controller is in the detent position. (See DJI-1026, 8-9.) Thus, Gold-Paper generally describes activating/de-activating response types based on movement of the controller in and out of detent. (See, e.g., DJI-1009, Figure 2.) Gold-Paper however does not explicitly disclose a “*directional control latch in data communication with the directional control architecture*” or “*activating the constant vector flat turn with a directional control latch.*”

247. Gold discloses a “*directional control latch*.” Gold’s flight control system includes logic which activates a constant vector flat turn when the pilot moves the directional controller out of detent. As I have discussed previously, Gold provides “an aircraft velocity command system which allows the pilot, during operation in a velocity stabilization mode, to yaw the aircraft from side to side without changing the inertial flight path of the aircraft.” (DJI-1005, 1:51-55.) Gold teaches that its control system activates a constant vector flat turn when the VCS is engaged, and command model 72 sends out yaw commands as the pilot moves the directional controller out of the detent position. Gold explains that the command model 72 “provides a desired attitude response signal” and “a desired yaw axis rate response, i.e., desired heading rate” to the velocity model 143 in the VCS. (DJI-1005, 5:9-13.) The pilot commands generated by moving the control stick out of detent are processed by the command model associated with the yaw control modules which shapes the pilot commands “to yield a desired rate and/or attitude response.” (DJI-1005, 4:6-7.) As I discussed in §V.B, the yaw control modules of the “*directional control architecture*” control movement in the yaw direction and receive shaped commands from a command model. In the absence of a yaw command being generated by the pilot via the control stick, no shaped command is generated by the command model 72 and the flat turn motion is not activated in

Gold. Therefore, the command model associated with the yaw control modules acts as a “*directional control latch*” that activates a constant vector flat turn as the pilot moves the directional controller out of a detent position.

248. The velocity stabilization mode logic of the combination of Gold, Shue, and Gold-Paper enables a constant vector flat turn motion. However, its functionality is activated only when the pilot moves the directional controller out of detent and the command model 72 sends a signal to the VCS. Accordingly, the command model includes “*a directional control latch in data communication with the directional control architecture*” [4A]/[14A]. The combination of Gold, Shue, Gold-Paper, and Skonieczny further discloses “*as the directional controller is moved out of a detent position, the directional control latch activates a contact flat turn motion*” [4B] and “*activating the constant vector flat turn with a directional control latch as the directional controller is moved out of a detent position*” [14].

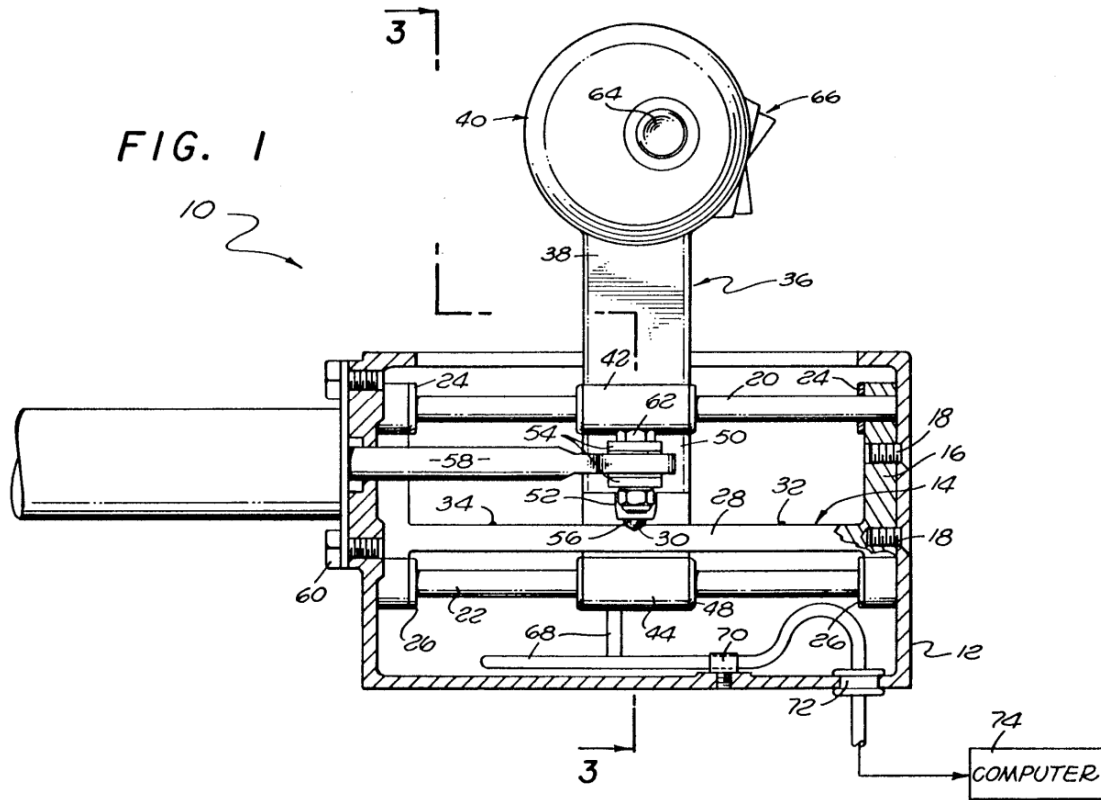
VI. GROUND 3: The combination of Gold, Shue, Gold-Paper, and Adams renders claims 7, 10, 17 and 20 obvious.

249. Claims 7, 10, 17, and 20 include limitations that claim “latches” that reset speed holds. Such speed-hold latches were known before the ’082 patent and were disclosed, for example, in U.S. Patent 5,065,962 to Adams, et al. (“Adams”). As established below, the combination of Gold, Shue, Gold-Paper and Adams renders claims 7, 10, 17, and 20 obvious.

A. Overview of the Combination

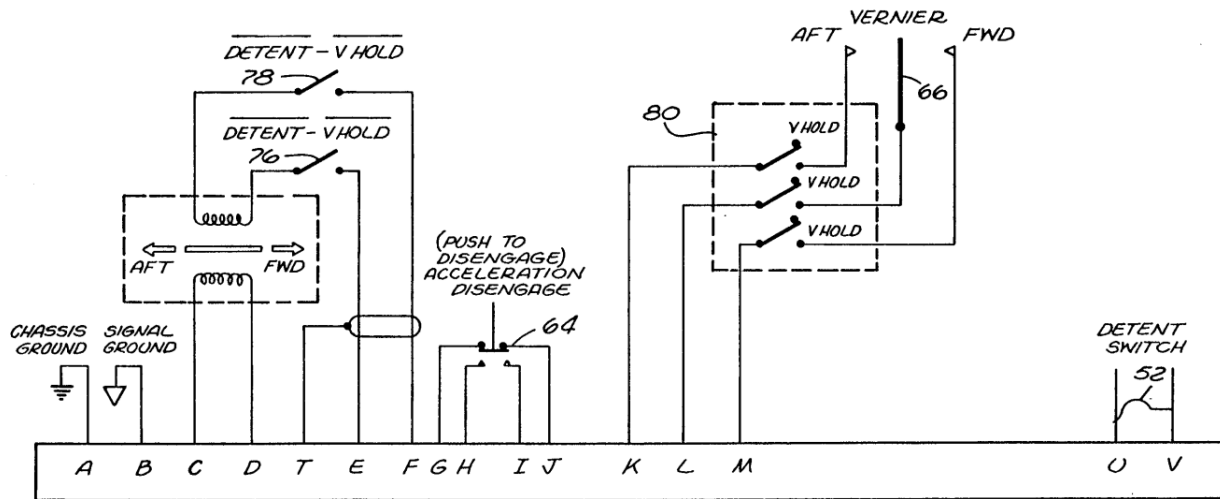
1. Adams

250. Adams relates “to a digital power controller used to command acceleration and deceleration rates and for maintaining a selected velocity.” (DJI-1007, 1:6-9.) Adams discloses a controller, illustrated in Figure 1, which has been reproduced below. The controller has a movable handle 36 with a handle shaft 38 that includes a protrusion 50 that “supports a detent switch 52.” (DJI-1007, 3:36-38.) The detent switch 52 “contains a roller ball 56 that rolls along the upper surface of the horizontal portion 28 of the linear cam 14.” (DJI-1007, 3:38-41.) Handle grip 40 “includes a velocity hold switch 64.” (DJI-1007, 3:45-46.) Wiring connects the switches to the computer 74. (DJI-1007, 3:49-56.)



Adams, Figure 1

251. The electric schematic of Adams' switching system is shown in Figure 4 below. "Movement of the handle from the detent groove depresses the detent switch 52." (DJI-1007, 3:57-58.) This action "sends a signal to the computer to check the phase of the signal from the linear transducer 58, closes switches 76 and 78, and **disengages velocity hold.**" (DJI-1007, 3:60-63.)



Adams, Figure 4

252. At the start of operation, Adams' handle 36 is in the neutral detent position with "rollerball 56 rest[ing] in detent groove 30." (DJI-1007, 4:6-8.) During forward movement, handle 36 "is moved to a position forward of the detent 30 along handle guides 20, 22." (DJI-1007, 4:9-11.) This action depresses the detent switch which "disengages velocity hold." (DJI-1007, 3:60-63.) The distance of handle 36 from detent groove 30 "determines the rate of increasing acceleration or rate of increasing deceleration." (DJI-1007, 4:13-16.) When the pilot obtains the desired airspeed, "velocity hold switch 64 is depressed," causing computer 74 "to select the current airspeed as the speed for velocity hold." (DJI-1007, 4:16-19.) Velocity hold "is maintained until the movable handle 36 is again removed from the central detent groove and moved either forward or aft." (DJI-1007, 4:30-33.)

2. Motivation to Combine Gold, Shue, Gold-Paper, and Adams

253. A POSITA would have been motivated to combine Adams' teachings regarding use of a switch to engage an operating mode and use of a detent switch to disengage the operating mode with Gold's sidearm controller and the flight control system of Gold, Shue, and Gold-Paper. Specifically, a POSITA would have been motivated to integrate the capability to determine when Gold's sidearm controller moves from the detent position and based on that determination instruct the flight control system of Gold, Shue, and Gold-Paper to disengage velocity stabilization mode and deactivate the lateral and longitudinal speed holds in place during velocity stabilization mode that are used to maintain the reference velocity. Adams' controller is described with reference to an aircraft capable of only forward longitudinal movement. Therefore, Adams only discloses a longitudinal detent switch. Because Gold's helicopter is capable of forward-backward (longitudinal) and side-side (lateral) movement initiated by the sidearm controller, a POSITA would have been motivated to incorporate a mechanism for determining when the sidearm controller moves out of the detent position in either the lateral or longitudinal direction and to disengage velocity stabilization mode and deactivate the associated lateral and longitudinal speed holds. Additionally, Adams, Gold,

Shue, and Gold-Paper are in the same field of endeavor as the '082 patent—controlling aircraft movement—and are therefore analogous art

254. A POSITA would have been motivated to make the above combination because Gold discloses helicopter operation in a velocity stabilization mode “in response to the manual activation of the velocity stabilization mode by the pilot” during which “the aircraft 10a yaws while maintaining a constant flight path reference velocity 12a with respect to an inertial frame of reference.” (DJI-1005, Abstract, 2:60-64.) However, aside from this disclosure and others like it, Gold does not provide any details regarding how velocity stabilization mode is engaged or how velocity stabilization mode is disengaged.

255. As I discussed previously, Gold-Paper describes response types within its velocity stabilization mode. Gold-Paper discloses control laws for the RAH-66 Comanche helicopter that “have been tailored to satisfy the requirements of ADS-33C”, an earlier version of ADS-33E discussed in DJI-1026. Response types typically include either the word “command” (e.g., translational rate command), the word “hold” (e.g., position hold), or both (e.g., yaw rate command/direction hold). (See DJI-1026, 6-10.) The term that immediately precedes the word “command” in a response type generally describes what the pilot is commanding when the pilot moves the corresponding pilot controller out of the detent position,

and the term that immediately precedes the word “hold” in a response type generally describes what the aircraft should try to maintain when the corresponding pilot’s controller is in the detent position. (*See* DJI-1026, 8-9.) For example, in Gold-Paper, when the helicopter is traveling at a groundspeed above a five-knot threshold, the pitch-axis response type is attitude command/velocity hold, meaning returning the longitudinal controller to the detent position automatically engages velocity hold and moving the longitudinal controller out of the detent position allows the pilot to directly control pitch attitude with the longitudinal controller. Gold-Paper discloses a similar response type for the roll-axis. When VELSTAB is engaged, “[t]he roll axis response type is AC/VH at low speeds, except when in the Hover Hold mode (VC/PH).” (DJI-1009, 421, *see also*, Figure 2.) Gold-Paper however does not explicitly describe “*a lateral control latch*” or a “*longitudinal control latch*” in “*data communication with the control system*”, “*resetting a lateral speed hold with a lateral control latch*”, or “*resetting a longitudinal speed hold with a longitudinal control latch*.”

256. A POSITA would have therefore been motivated to search for references describing techniques for engaging/disengaging an operating mode involving a speed/velocity hold with a latch and would have been led to Adams. Moreover, a POSITA would have been motivated to combine Gold, Shue, Gold-

Paper, and Adams because (1) the combination is merely the use of a known technique (Adams' technique to determine when a controller moves out of detent and signal the computer to disengage velocity hold) to improve similar devices (Gold's sidearm controller and flight control system) in the same way (providing the ability to engage/disengage velocity hold); (2) the combination applies a known technique (Adams' technique to determine when a controller moves out of detent and signal the computer to disengage velocity hold) to a known device (Gold's sidearm controller and flight control system) ready for improvement (providing the ability for the pilot to engage or disengage velocity hold); and (3) the combination also combines prior art elements (Adams' technique to determine when a controller moves out of detent and signal the computer to disengage velocity hold with the sidearm controller and flight control system of Gold, Shue, and Gold-Paper having a velocity stabilization mode having lateral and longitudinal speed holds) according to known methods.

257. A POSITA would have had reasonable expectation of success in the combination and the results of the combination would have been predictable because both relate to pilots' controllers. Gold discloses that its sidearm controller provides "force output command signals" to the PFCS and AFCS of the flight control system of Gold, Shue, and Gold-Paper. (DJI-1005, 3:10-11.) The

combination therefore merely adds an additional signal that indicates the directional force (lateral or longitudinal) and commands the flight control system to disengage velocity stabilization mode (and deactivate lateral and longitudinal speed holds in use during that mode). Moreover, Gold's sidearm controller was well-known in the art before the earliest possible priority date of the '082 patent as I discussed in §III.A. Therefore, a POSITA would have understood and been able to apply Adams' teachings to the controller architecture of the combination of Gold, Shue, and Gold-Paper.

B. “*Lateral Control Latch*”

258. Claims 7 and 17, reproduced below, are directed to a “*lateral control latch*” that resets a lateral speed hold.

7. The control system of claim 6, further comprising:

[7A] a lateral control hatch in data communication with the control system;

[7B] wherein, as the lateral controller is moved out of a detent position, the lateral control latch resets a lateral speed hold.

17. The method of claim 11, further comprising:

resetting a lateral speed hold with a lateral control hatch as the lateral controller is moved out of a detent position.

259. The combination of Gold, Shue, Gold-Paper, and Adams discloses “a lateral control latch” that “resets a lateral speed hold.” In the combined system of Gold, Shue, Gold-Paper, and Adams, the sidearm controller includes the capability to determine when the controller is moved laterally out of the detent position and to disengage velocity stabilization mode which deactivates the lateral speed hold. When the “lateral controller is moved out of a detent position” by moving the sidearm controller right or left, the detent detection capability activates, sending a signal to the flight control computer indicating direction of controller movement and rate of acceleration and commanding the system to disengage velocity hold. This process resets the lateral speed hold in place during velocity stabilization mode to maintain the reference velocity. Thus, the combination of Gold and Adams discloses “a lateral control latch in data communication with the control system” [7A], “as the lateral controller is moved out of a detent position, the lateral control latch resents a lateral speed hold” [7B], and “resetting a lateral speed hold with a lateral control latch as the lateral controller is moved out of a detent position” [17].

260. Should an argument be made that the sidearm controller is not part of the “control system” and, therefore, the combination fails to disclose a “control system” comprising “a lateral control latch” as recited in claim 7, I disagree.

Claim 6 of the '082 patent recites that the “*control system*” comprises “*a lateral controller*” that is “*manipulated by the pilot.*” Because the “*lateral controller*” is part of the “*control system*”, its components, including the “*latch*” are also part of the “*control system.*” Regardless, a POSITA would have understood how to integrate a similar software “latching” function as performed by the detent switch of Adams in the flight control system of Gold, Shue, and Gold-Paper.

C. “*Longitudinal Control Latch*”

261. Claims 10 and 20, reproduced below, are directed to a “*longitudinal control latch.*”

10. The control system of claim 9, further comprising:

[10A] a longitudinal control latch in data communication with the control system;

[10B] wherein, as the longitudinal controller is moved out of a detent position, the longitudinal control latch resets a longitudinal speed hold.

20. The method of claim 19, further comprising:

resetting a longitudinal speed hold with a longitudinal control latch as the longitudinal controller is moved out of a detent position, the longitudinal control latch being in data communication with the longitudinal control architecture.

262. The combination of Gold, Shue, Gold-Paper, and Adams discloses “a *longitudinal control latch*” that “*resets a longitudinal speed hold.*” In the combined system of Gold, Shue, Gold-Paper and Adams, the sidearm controller includes the capability to determine when the controller is moved longitudinally out of the detent position and to disengage velocity stabilization mode which deactivates the longitudinal speed hold. When the “*longitudinal controller is moved out of a detent position*” by moving the sidearm controller forward or backward, the detent detection capability activates, sending a signal to the flight control computer indicating direction of controller movement and rate of acceleration and commanding the system to disengage velocity hold. This process resets the longitudinal speed hold in place during velocity stabilization mode to maintain the reference velocity. Thus, the combination of Gold and Adams discloses “a *longitudinal control latch in data communication with the control system*” [10A], “*as the longitudinal controller is moved out of a detent position, the longitudinal control latch resents a longitudinal speed hold*” [10B], and “*resetting a longitudinal speed hold with a longitudinal control latch as the longitudinal controller is moved out of a detent position*” [20].

263. Should an argument be made that the sidearm controller is not part of the “*control system*” and therefore the combination of Gold, Shue, Gold-Paper, and

Adams fails to disclose a “*control system*” comprising “*a longitudinal control latch*” as recited in claim 10, I disagree. Claim 9 of the ’082 patent recites that the “*longitudinal control architecture*” comprises “*a longitudinal controller*” that is “*manipulated by the pilot.*” Because the “*longitudinal controller*” is part of the “*control system*”, its components, including the “*latch*” are also part of the “*control system*.” Regardless, a POSITA would have understood how to integrate a similar software “latching” function as performed by the detent switch of Adams in the flight control system of Gold, Shue, and Gold-Paper.

VII. Conclusion

264. In signing this declaration, I recognize that the declaration will be filed as evidence in a contested case before the Patent Trial and Appeal Board of the United States Patent and Trademark Office. I also recognize that I may be subject to cross-examination in the case and that cross-examination will take place within the United States. If cross-examination is required of me, I will appear for cross-examination within the United States during the time allotted for cross-examination.

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code.

Executed this 28th day of July in Atlanta, GA.

Respectfully submitted,



William Singhose

APPENDIX

Exhibit	Reference
1001	U.S. Patent 8,332,082 to Christensen et al. (“the ’082 patent”)
1002	File History of U.S. Patent 8,332,082
1005	U.S. Patent 5,553,812 to Gold, et al. (“Gold”)
1006	U.S. Patent 5,238,203 to Skonieczny, et al. (“Skonieczny”)
1007	U.S. Patent 5,065,962 to Adams, et al. (“Adams”)
1008	U.S. Patent Publication 2008/0097658 to Shue, et al. (“Shue”)
1009	“Design and Pilot Evaluation of the RAH-66 Comanche Selectable Control Modes” by Gold, et al. (“Gold-Paper”)
1011	EP 2673681 B1 to Christensen, et al (“Companion EP Patent”)
1012	Prosecution History of EP 2673681
1013	U.S. Patent Publication 2010/0324758 to Piasecki, et al (“Piasecki”)
1014	U.S. Patent 5,001,646 to Caldwell, et al (“Caldwell”)
1015	U.S. Department of Transportation, Federal Aviation Administration, “Rotorcraft Flying Handbook”, FAA-H-8083-21 (2000)
1016	U.S. Department of Transportation, Federal Aviation Administration, “Helicopter Flying Handbook”, FAA-H-8083-21B (2019) (“Helicopter Flying Handbook”)
1017	Excerpts from “Aircraft Dynamics and Automatic Control” by McRuer, et al (Princeton Legacy Library 1973) (“McRuer”)
1018	“Flight Stability and Automatic Control”, Second Edition, by Nelson (WCB/McGraw-Hill 1998) (“Nelson”)
1019	“Mechanics of Flight” by Phillips (John Wiley & Sons 2004) (“Mechanics of Flight”)
1020	“Advanced Flight Control Research and Development at Boeing Helicopters” by Landis, et al in “Advances in Aircraft Flight Control” (1996)

Exhibit	Reference
1021	“The Characteristics of Model-Following Systems as Synthesized by Optimal Control” by Tyler, IEEE Transactions on Automatic Control, October 1964 (“Tyler”)
1022	“Input-Shaping and Model-Following Control of a Helicopter Carrying a Suspended Load” by Adams, et al, Journal of Guidance, Control, and Dynamics, Vol. 38, No. 1, January 2015 (“Adams”)
1023	Excerpt from “Dynamics of Helicopter Flight” by Saunders (1975)
1024	“Helicopter Aerodynamics-Aircraft Theory of Flight”
1025	File History of U.S. Patent 8,682,505
1026	“Aeronautical Design Standard Performance Specification, Handling Qualities Requirements for Military Rotorcraft”, ADS-33E-PRF (March 21, 2000)