(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
2 June 2016 (02.06.2016)

(10) International Publication Number
WO 2016/085564 A1

(51) International Patent Classification:
B64C 5/10 (2006.01) *G05D 1/08* (2006.01)
B64C 27/57 (2006.01)

(21) International Application Number: PCT/US2015/051928

(22) International Filing Date: 24 September 2015 (24.09.2015)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
62/084,268 25 November 2014 (25.11.2014) US

(71) Applicant: **SIKORSKY AIRCRAFT CORPORATION** [US/US]; 6900 Main Street, P.O. Box 9729, Stratford, Connecticut 06615-9129 (US).

(72) Inventor: **WULFF, Ole**; 16 Woodlawn Ave., Ansonia, Connecticut 06401 (US).

(74) Agent: **FOX, David A.**; Cantor Colburn LLP, 20 Church Street, 22nd Floor, Hartford, Connecticut 06103-3207 (US).

(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

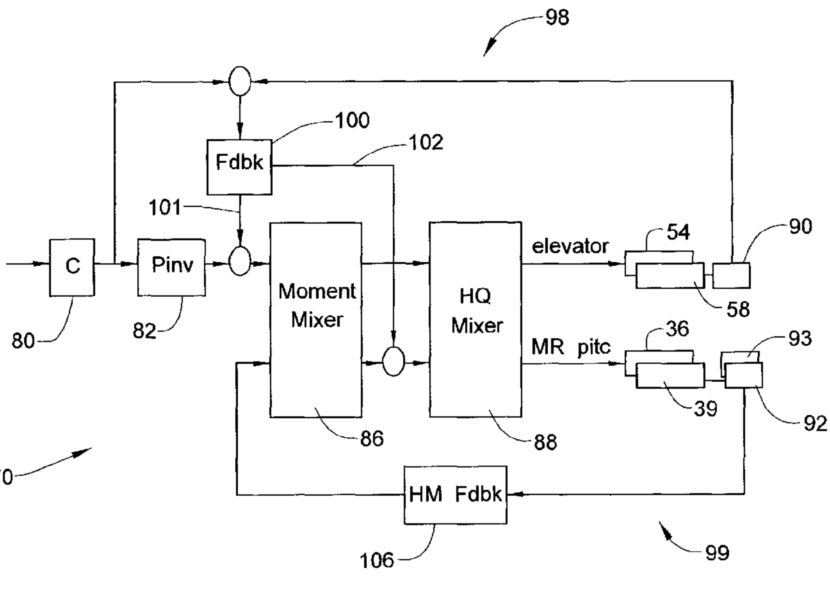
(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Declarations under Rule 4.17:
— *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*
— *as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))*
— *of inventorship (Rule 4.17(iv))*

[Continued on next page]

(54) Title: FLIGHT CONTROL SYSTEM FOR A ROTARY WING AIRCRAFT

FIG. 3



(57) **Abstract**: A rotary wing aircraft includes an airframe including an extending tail. The airframe includes a longitudinal axis that extends through the extending tail. The rotary wing aircraft also includes a main rotor assembly including at least one rotor hub supporting a plurality of rotor blades configured and disposed to rotate about a main rotor axis, at least one elevator arranged at the extending tail, and a control system operably connected to the main rotor assembly and the at least one elevator. The control system is configured and disposed to adjust each of a pitch rate and an attitude of the airframe by selectively adjusting a position of the at least one elevator.

WO 2016/085564 A1

Published:

— *with international search report (Art. 21(3))*

FLIGHT CONTROL SYSTEM FOR A ROTARY WING AIRCRAFT

STATEMENT OF FEDERAL SUPPORT

[0001] This invention was made with Government support under contract number W911W6-13-2-0013 awarded by the United States Army under the AATD TIA. The Government has certain rights in the invention.

BACKGROUND OF THE INVENTION

[0002] Exemplary embodiments pertain to the art of rotary wing aircraft and, more particularly, to a flight control system for a rotary wing aircraft.

[0003] Rotary wing aircraft rely on a main rotor for pitch and attitude control. More specifically, a pilot manipulates a cyclic to adjust an angle of attack (AOA) of the main rotor to change pitch and/or attitude characteristics of the aircraft. A tail rotor is generally employed to control yaw characteristics. By controlling the AOA of the main rotor and controlling the tail rotor, a pilot may maneuver the rotary wing aircraft.

BRIEF DESCRIPTION OF THE INVENTION

[0004] Disclosed is a rotary wing aircraft including an airframe including an extending tail. The airframe includes a longitudinal axis that extends through the extending tail. The rotary wing aircraft also includes a main rotor assembly including at least one rotor hub supporting a plurality of rotor blades configured and disposed to rotate about a main rotor axis, at least one elevator arranged at the extending tail, and a control system operably connected to the main rotor assembly and the at least one elevator. The control system is configured and disposed to adjust each of a pitch rate and an attitude of the airframe by selectively adjusting a position of the at least one elevator.

[0005] In addition to one or more of the features described above or below, or as an alternative, further embodiments include wherein the control system includes a moment mixer and a handling quality (HQ) mixer.

[0006] In addition to one or more of the features described above or below, or as an alternative, further embodiments include a hub moment sensor operably connected to the main rotor assembly.

[0007] In addition to one or more of the features described above or below, or as an alternative, further embodiments include a hub moment estimator operably connected to the control system.

[0008] In addition to one or more of the features described above or below, or as an alternative, further embodiments include wherein the control system includes a hub moment feedback system operably connected to the hub moment sensor and the rotor hub and the moment mixer, wherein the control system selectively adjusts rotor hub moment based on an input from the hub moment feedback system.

[0009] In addition to one or more of the features described above or below, or as an alternative, further embodiments include an attitude/pitch rate sensor operably connected to the airframe.

[0010] In addition to one or more of the features described above or below, or as an alternative, further embodiments include wherein the control system includes a pitch rate and attitude feedback system operably connected to the attitude/pitch rate sensor and each of the moment mixer and the handling quality (HQ) mixer, wherein the control system selectively adjusts a position of the at least one elevator based on an input from the pitch rate and attitude feedback system.

[0011] In addition to one or more of the features described above or below, or as an alternative, further embodiments include a translational thrust system including at least one propeller configured to rotate about a thrust axis that is substantially parallel to the longitudinal axis, the control system being configured and disposed to selectively adjust a pitch of the at least one propeller to control forward and rearward motion of the airframe.

[0012] In addition to one or more of the features described above or below, or as an alternative, further embodiments include wherein the at least one rotor hub includes a first rotor hub supporting a first plurality of rotor blades and a second rotor hub supporting a second plurality of rotor blades, the main rotor assembly defining a co-axial rotor assembly.

[0013] In addition to one or more of the features described above or below, or as an alternative, further embodiments include wherein the at least one elevator includes a first elevator arranged on a starboard side of the longitudinal axis and a second elevator arranged on a port side of the longitudinal axis

[0014] Also disclosed is a method of controlling a rotary wing aircraft. The method includes selectively adjusting a position of at least one elevator to control at least one of a pitch and an attitude of the rotary wing aircraft.

[0015] In addition to one or more of the features described above or below, or as an alternative, further embodiments include sensing a pitch and an attitude with an attitude/pitch rate sensor mounted to an airframe of the rotary wing aircraft, and generating a first feedback signal from the sensed pitch and attitude, the first feedback signal being introduced into a moment mixer to selectively adjust the position of the elevator.

[0016] In addition to one or more of the features described above or below, or as an alternative, further embodiments include wherein the first feedback signal represents a fast feedback signal, the fast feedback signal defining a difference between a command model input and an actual position of the airframe to reduce model inaccuracies of the command model input.

[0017] In addition to one or more of the features described above or below, or as an alternative, further embodiments include generating a second feedback signal from the sensed pitch and attitude, the second feedback signal being distinct from the first feedback signal and introduced into a handling quality (HQ) mixer to selectively adjust pitch of one or more rotor blades operably coupled to a main rotor assembly, wherein the second feedback signal represents a slow feedback signal, the slow feedback signal adjusting for changes in trim points of the airframe.

[0018] In addition to one or more of the features described above or below, or as an alternative, further embodiments include sensing main rotor hub moment through a hub moment sensor, and generating a hub moment feedback signal from the hub moment sensor, the hub moment feedback signal being introduced into the moment mixer to selectively adjust pitch of one or more rotor blades operably coupled to a main rotor assembly.

[0019] In addition to one or more of the features described above or below, or as an alternative, further embodiments include configuring the first feedback signal with at least one flight regime parameter.

[0020] In addition to one or more of the features described above or below, or as an alternative, further embodiments include driving a main rotor assembly including a first rotor hub supporting a first plurality of rotor blades and a second rotor hub supporting a second plurality of rotor blades.

BRIEF DESCRIPTION OF THE DRAWINGS

[0021] The following descriptions should not be considered limiting in any way. With reference to the accompanying drawings, like elements are numbered alike:

[0022] FIG. 1 depicts a rotary wing aircraft, in accordance with an exemplary embodiment;

[0023] FIG. 2 is a perspective view of a rotary wing aircraft, in accordance with an exemplary embodiment; and

[0024] FIG. 3 is a schematic diagram illustrating a control system of the rotary wing aircraft, in accordance with an exemplary embodiment.

DETAILED DESCRIPTION OF THE INVENTION

[0025] A detailed description of one or more embodiments of the disclosed apparatus and method are presented herein by way of exemplification and not limitation with reference to the Figures.

[0026] FIGs. 1and 2 depict an exemplary embodiment of a rotary wing, vertical takeoff and land (VTOL) aircraft 10. The aircraft 10 includes an airframe 12 with an extending tail 14. A dual, counter rotating, coaxial main rotor assembly 18 is located at the airframe 12 and rotates about a main rotor axis, A. In an exemplary embodiment, the airframe 12 includes a cockpit 15 having two seats for flight crew (e.g., pilot and co-pilot) and six seats for passengers (not shown). Main rotor assembly 18 is driven by a power source, for example, one or more engines 24 via a gearbox 26. Main rotor assembly 18 includes an upper rotor assembly 28 driven in a first direction (e.g., counter-clockwise) about the main rotor axis, A, and a lower rotor assembly 32 driven in a second direction (e.g., clockwise) about the main rotor axis, A, opposite to the first direction (i.e., counter rotating rotors). Upper rotor assembly 28 includes a first plurality of rotor blades 34 supported by a first rotor hub 36. Lower rotor assembly 32 includes a second plurality of rotor blades 38 supported by a second rotor hub 39. In some embodiments, the aircraft 10 further includes a translational thrust system 40 having a propeller 42 located at the extending tail 14 to provide translational thrust (forward or rearward) for aircraft 10. Propeller 42 includes a plurality of blades 43.

[0027] Main rotor assembly 18 includes a rotor hub fairing 44 generally located between and around the upper and lower rotor assemblies 28 and 32 such that rotor hub 36 and rotor hub 39 are at least partially contained therein. Rotor hub fairing 44 provides drag reduction. First plurality of rotor blades 34 is connected to rotor hub 36 in a hingeless manner, also referred to as a rigid rotor system. Similarly, second plurality of rotor blades 38 is connected to rotor hub 39 in a hingeless manner. In accordance with an aspect of the exemplary embodiment, upper and lower rotor assemblies 28 and 32 rotate about a fixed axis. Although a particular aircraft configuration is illustrated in this non-limiting embodiment, other rotary wing aircraft will also benefit from embodiments of the invention. Although, the dual rotor system is depicted as coaxial, embodiments include dual rotor aircraft having non-coaxial rotors.

[0028] Propeller 42, or translational thrust system 40, is connected to, and driven by, the engine 24 via the gearbox 26. Translational thrust system 40 may be mounted to the rear of the airframe 12 with a translational thrust axis, T, oriented substantially horizontal and parallel to the aircraft longitudinal axis, L, to provide thrust for high-speed flight. The term “parallel” should be understood to include a translational thrust axis that is coincident with the longitudinal axis. Translational thrust axis, T, corresponds to the axis of rotation of propeller 42. While shown in the context of a pusher-prop configuration, it is understood that the propeller 42 could also be a more conventional puller prop or could be variably facing so as to provide yaw control in addition to, or instead of, translational thrust. It should be understood that any such system or other translational thrust systems may alternatively or additionally be utilized. Alternative translational thrust systems may include different propulsion forms, such as a jet engine.

[0029] In accordance with an aspect of an exemplary embodiment, propeller blades 43 of translational thrust system 40 may include a variable pitch. More specifically, the pitch of propeller blades 43 may be altered to change the direction of thrust (e.g., forward or rearward). In accordance with another aspect of an exemplary embodiment, extended tail 14 includes a tail section 50 including starboard and port horizontal stabilizers 51 and 52. Tail section 50 also includes a vertical stabilizer 53 that extends downward from extending tail 14. Starboard horizontal stabilizer 51 includes a starboard active elevator 54 and a starboard active rudder 56. Similarly, port horizontal stabilizer 52 includes a port active elevator 58 and a port active rudder 60. Elevators 54 and 58 and rudders 56 and 60 act as controllable surfaces, e.g., surfaces that alter a flight path/characteristics of aircraft 10.

[0030] Referring to FIG. 3, in accordance with an exemplary embodiment, aircraft 10 includes a control system 70 which, as will be detailed more fully below, adjusts attitude and pitch of airframe 12 by selectively manipulating/adjusting elevators 54 and 58. Control system 70 includes a command model module 80 that is operatively connected to one or more control members (not shown) arranged in cockpit 15. The pilot and/or co-pilot manipulate the one or more control members to adjust flight characteristics of aircraft 10. Command model module 80 is operably connected to an inverse plant module 82 which outputs an inverse control signal. Inverse plant module 82 is operably connected to a moment mixer 86 which controls hub moment. Moment mixer 86 is operably connected to a handling quality (HQ) mixer 88 which controls handling characteristics of aircraft 10. HQ mixer 88 is operably connected to elevators 54 and 58 and rotor hubs 36 and 39. Control system 70 also includes an attitude/pitch rate sensor 90 and a hub moment sensor 92. Hub moment sensor

92 may take the form of a hub moment estimator 93. The particular location of attitude/pitch rate sensor 90 and hub moment sensor 92 and/or hub moment estimator 93 may vary. Hub moment estimator 93 may provide an estimate of hub moment thereby eliminating the need to sense actual hub moment.

[0031] In further accordance with an exemplary embodiment, control system 70 includes a first or pitch/attitude feedback system 98 and a second or hub moment feedback system 99. First feedback system 98 includes a first feedback module 100 operably connected to command model module 80, moment mixer 86, HQ mixer 88 and attitude/pitch rate sensor 90. First feedback module 100 outputs a first or fast feedback signal 101 to moment mixer 86 and a second or slow feedback signal 102 to HQ mixer 88. First or fast feedback signal 101 represents a difference between actual aircraft attitude/pitch rate as sensed by attitude/pitch rate sensor 90 and a model attitude/pitch rate response provided by command model module 80.

[0032] First feedback signal 101 is combined with the inverse control signal and passed to moment mixer 86 and HQ mixer 88. Moment mixer 86 and HQ mixer 88 employ first feedback signal 101 and the inverse control signal to establish a desired position of elevators 54 and 58 to control attitude and pitch rate. That is, in contrast to existing rotary wing aircraft which rely on manipulating a position of the main rotor, attitude and pitch rate of aircraft 10 is adjusted through the manipulation of elevators 54 and 58. First feedback signal 101 allows control system 70 to further control elevators 54 and 58 to adjust flight characteristics of aircraft 10 to provide desired stability, and provide disturbance rejection, e.g., account for wind gusts and other anomalies that may alter flight characteristics. More specifically, command model module 80 provides a desired position output for elevators 54 and 58. However, command model module 80 does not, itself, adjust for various anomalies that may affect aircraft 10. Second feedback signal 102 is passed to HQ mixer 88 to establish hub moment trim point control of aircraft 10. In addition, moment mixer 86 may receive a flight regime parameter (FRP) such as airspeed, aircraft weight, air density, air temperature altitude, and the like. The FRP may also be employed to configure HQ mixer 88 as well as enhance feedback quality from pitch/attitude feedback system 98 and a second or hub moment feedback system 99. Second feedback system 99 includes a second feedback module 106 that is connected between hub moment sensor 92 and moment mixer 86. Second feedback system 99 provides an actual hub moment signal to moment mixer 86. Moment mixer 86 selectively generates an output signal to reduce rotor hub moment excursions based on the actual hub moment. In this manner, control system 70 decouples hub moment control and elevator control to reduce hub moment while maintaining desirable flight characteristics of aircraft 10.

[0033] While the invention has been described with reference to an exemplary embodiment or embodiments, it will be understood by those skilled in the art that various changes may be made and equivalents may be substituted for elements thereof without departing from the scope of the invention. In addition, many modifications may be made to adapt a particular situation or material to the teachings of the invention without departing from the essential scope thereof. Therefore, it is intended that the invention not be limited to the particular embodiment disclosed as the best mode contemplated for carrying out this invention, but that the invention will include all embodiments falling within the scope of the claims.

CLAIMS

What is claimed is:

1. A rotary wing aircraft comprising:

an airframe including an extending tail, the airframe including a longitudinal axis that extends through the extending tail;

a main rotor assembly including at least one rotor hub supporting a plurality of rotor blades configured and disposed to rotate about a main rotor axis;

at least one elevator arranged at the extending tail; and

a control system operably connected to the main rotor assembly and the at least one elevator, the control system being configured and disposed to adjust each of a pitch rate and an attitude of the airframe by selectively adjusting a position of the at least one elevator.

2. The rotary wing aircraft according to claim 1, wherein the control system includes a moment mixer and a handling quality (HQ) mixer.

3. The rotary wing aircraft according to claims 1 or 2, further comprising: a hub moment sensor operably connected to the main rotor assembly.

4. The rotary wing aircraft according to claims 1 or 2 further comprising: a hub moment estimator operably connected to the control system.

5. The rotary wing aircraft according to claim 3, wherein the control system includes a hub moment feedback system operably connected to the hub moment sensor and the rotor hub and the moment mixer, wherein the control system selectively adjusts rotor hub moment based on an input from the hub moment feedback system.

6. The rotary wing aircraft according to claim 2 or claim 3, further comprising: an attitude/pitch rate sensor operably connected to the airframe.

7. The rotary wing aircraft according to claim 6, wherein the control system includes a pitch rate and attitude feedback system operably connected to the attitude/pitch rate sensor and each of the moment mixer and the handling quality (HQ) mixer, wherein the control system selectively adjusts a position of the at least one elevator based on an input from the pitch rate and attitude feedback system.

8. The rotary wing aircraft according to claim 1, further comprising: a translational thrust system including at least one propeller configured to rotate about a thrust axis that is substantially parallel to the longitudinal axis, the control system being configured and disposed to selectively adjust a pitch of the at least one propeller to control forward and rearward motion of the airframe.

9. The rotary wing aircraft according to claim 1, wherein the at least one rotor hub includes a first rotor hub supporting a first plurality of rotor blades and a second rotor hub supporting a second plurality of rotor blades, the main rotor assembly defining a co-axial rotor assembly.

10. The rotary wing aircraft according to claim 1, wherein the at least one elevator includes a first elevator arranged on a starboard side of the longitudinal axis and a second elevator arranged on a port side of the longitudinal axis.

11. A method of controlling a rotary wing aircraft comprising:

selectively adjusting a position of at least one elevator to control at least one of a pitch and an attitude of the rotary wing aircraft.

12. The method of claim 10, further comprising:

sensing a pitch and an attitude with an attitude/pitch rate sensor mounted to an airframe of the rotary wing aircraft; and

generating a first feedback signal from the sensed pitch and attitude, the first feedback signal being introduced into a moment mixer to selectively adjust the position of the elevator.

13. The method of claim 12, wherein the first feedback signal represents a fast feedback signal, the fast feedback signal defining a difference between a command model input and an actual position of the airframe to reduce model inaccuracies of the command model input.

14. The method of claim 12, further comprising: generating a second feedback signal from the sensed pitch and attitude, the second feedback signal being distinct from the first feedback signal and introduced into a handling quality (HQ) mixer to selectively adjust pitch of one or more rotor blades operably coupled to a main rotor assembly, wherein the second feedback signal represents a slow feedback signal, the slow feedback signal adjusting for changes in trim points of the airframe.

15. The method of claim 12, further comprising:

sensing main rotor hub moment through a hub moment sensor; and

generating a hub moment feedback signal from the hub moment sensor, the hub moment feedback signal being introduced into the moment mixer to selectively adjust pitch of one or more rotor blades operably coupled to a main rotor assembly.

16. The method of claim 12, further comprising:

estimating main rotor hub moment through a hub moment estimator; and generating a hub moment feedback signal from the hub moment sensor, the hub moment feedback signal being introduced into the moment mixer to selectively adjust pitch of one or more rotor blades operably coupled to a main rotor assembly.

17. The method of claim 12, further comprising: configuring the first feedback signal with at least one flight regime parameter (FRP).

18. The method of claim 11, further comprising: driving a main rotor assembly including a first rotor hub supporting a first plurality of rotor blades and a second rotor hub supporting a second plurality of rotor blades.

FIG. 1

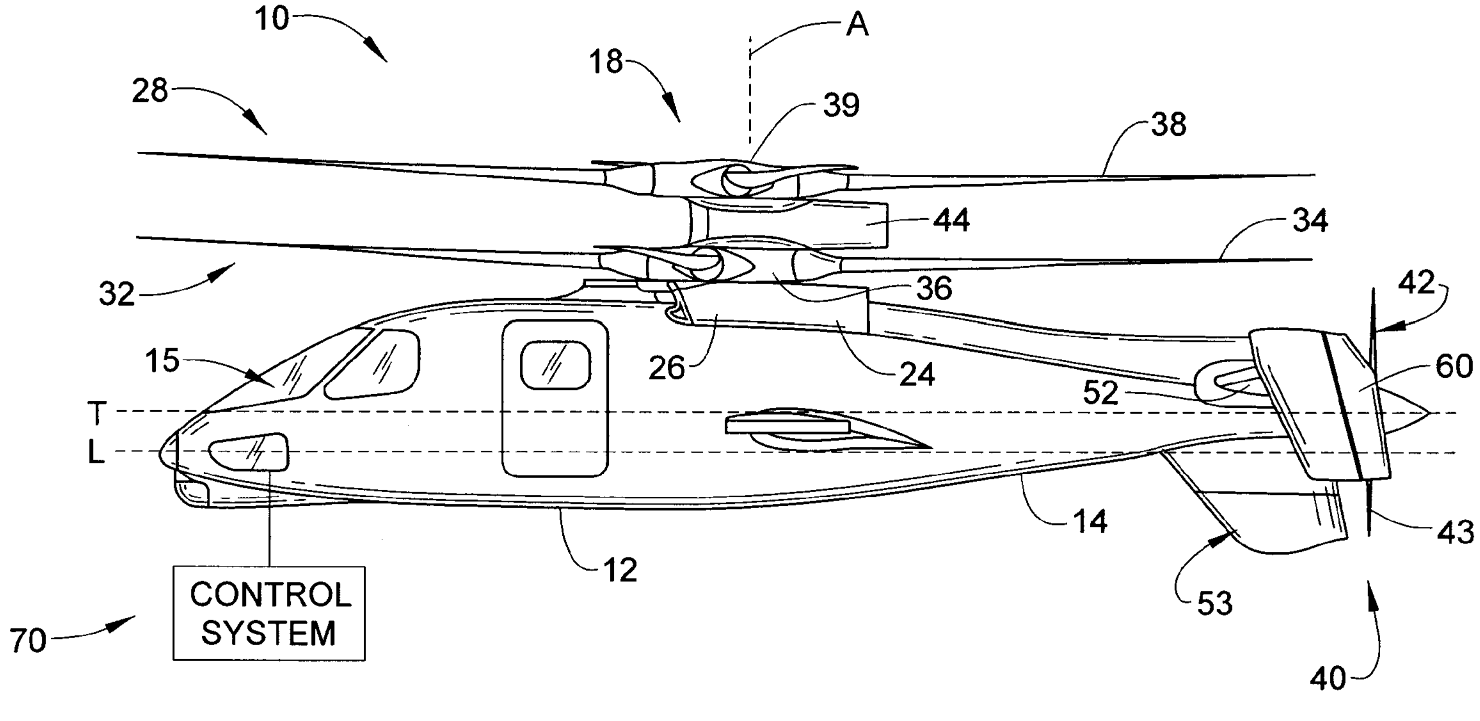

10
A
18
28
39
38
44
34
32
36
42
15
26
24
60
52
T
L
14
43
12
53
CONTROL
SYSTEM
70
40

FIG. 2

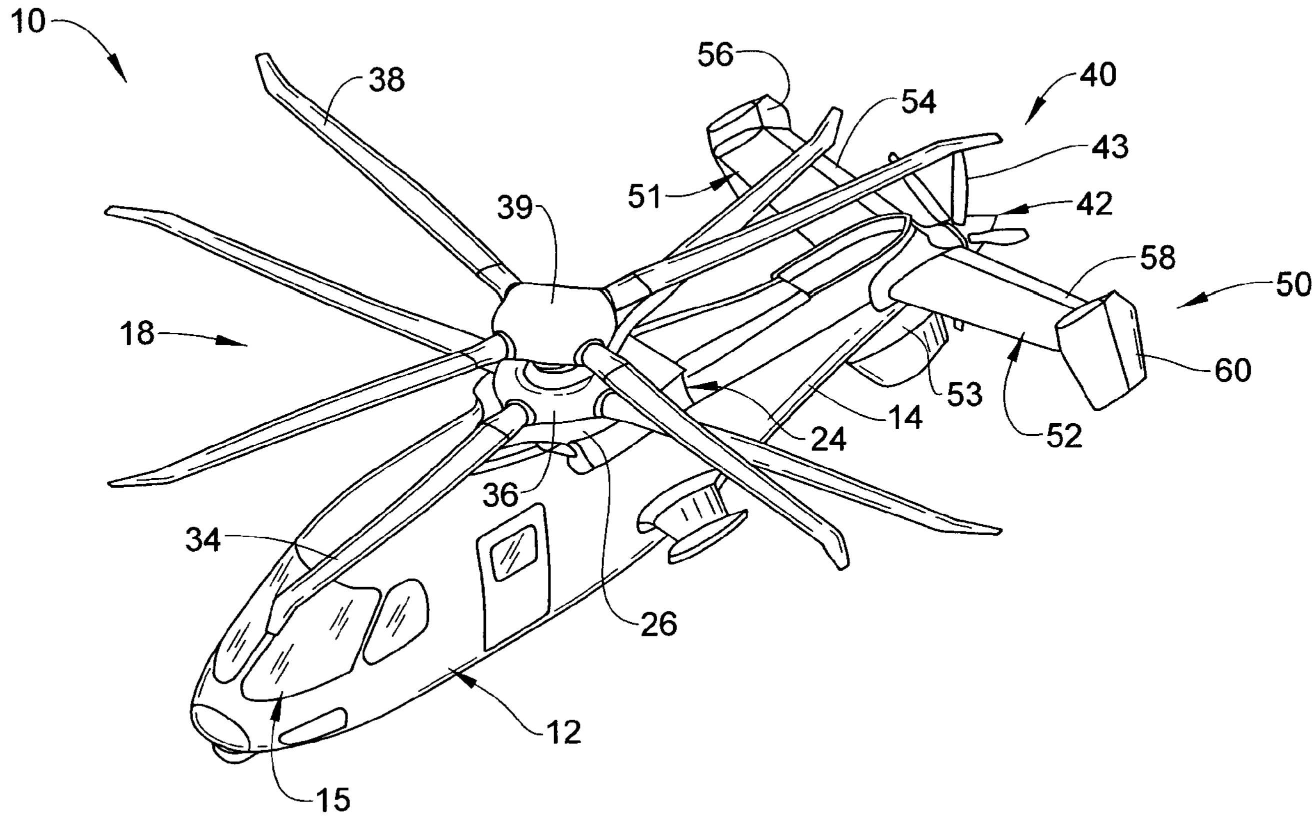
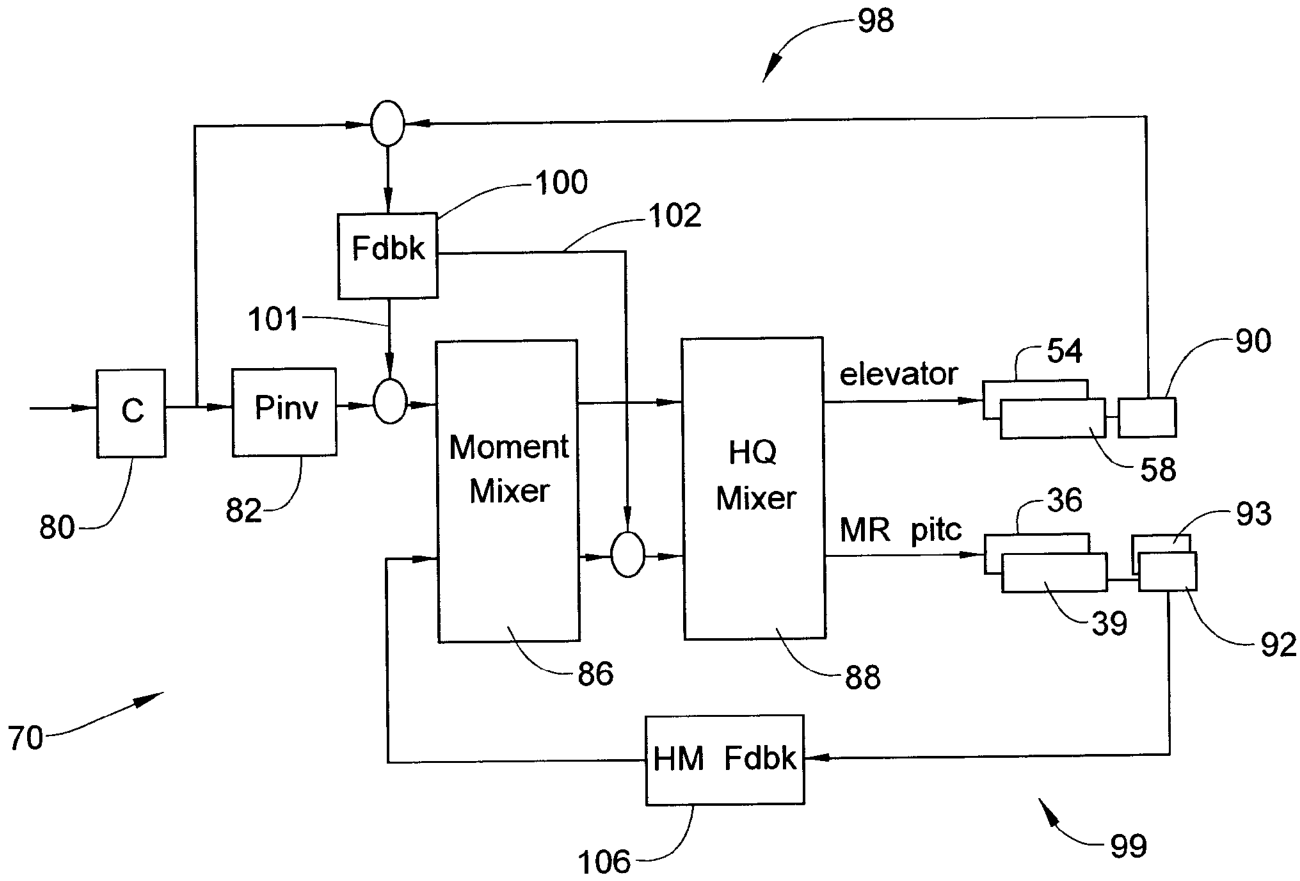


FIG. 3


98
100
102
Fdbk
101
C
Pinv
Moment
Mixer
HQ
Mixer
elevator
54
90
58
80
82
MR pitc
36
93
39
92
86
88
70
HM Fdbk
106
99

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US15/51928

A. CLASSIFICATION OF SUBJECT MATTER
IPC(8) - B64C 5/10, 27/57; G05D 1/08 (2016.01)
CPC - B64C 5/10, 27/57; G05D 1/0816
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC(8) Classification(s): B64C 5/10, 11/30, 11/34, 17/00, 19/00, 27/54, 27/57; G05D1/08 (2016.01)
CPC Classification(s): B64C 5/10, B64C 11/30, 11/308, 11/34, 17/00, 19/00, 27/54, 27/57; G05D 1/0808, 1/0816, 1/0825

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
PatSeer (US, EP, WO, JP, DE, GB, CN, FR, KR, ES, AU, IN, CA, INPADOC Data); Google; Google/Scholar; EBSCO; Keywords: elevator*, stabilator*, tail*, stabilizer*, empennage*, control*, adjust*, chang*, mov*, pitch*, moment*, torque*, mixer*, feedback*, signal*, sens*, measure*, determin*, detect*, gaug*, mix*, sum*, rotor*, hub*, mast*, propeller*, blade*, cyclic*

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X ------- Y	US 2009/0321554 A1 (ROESCH P) December 31, 2009; figures 1, 3; paragraphs [0115], [0158], [0182], [0186]-[0191], [0197]	1, 2, 3/1, 3/2, 4/1, 4/2, 5/3/1, 5/3/2, 8, 10, 11 ------- 12-17
X	US 2009/0159740 A1 (BRODY DE et al.) June 25, 2009; figures 1-3; paragraphs [0028], [0035], [0036], [0055]	1, 9, 11, 18
Y	US 2014/0236399 A1 (AIRBUS OPERATIONS) August 21, 2014; figures 2, 3; paragraphs [0013], [0024], [0035], [0042], [0078], [0089], [0091], [0095]-[0097], [0100]	12-17
Y	US 2010/0178167 A1 (JANKER P et al.) July 15, 2010; figure 3; paragraph [0015], [0019], [0035], [0036]	15, 16
A	US 4,304,375 A (BUILTA KE et al.) December 8, 1981; entire document	1, 2, 3/1, 3/2, 4/1, 4/2, 5/3/1, 5/3/2, 8-18
A	US 2014/0084105 A1 (EUROCOPTER) March 27, 2014; entire document	1, 2, 3/1, 3/2, 4/1, 4/2, 5/3/1, 5/3/2, 8-18
A	US 2011/0057071 A1 (SAHASRABUDHE V et al.) March 10, 2011; entire document	1, 2, 3/1, 3/2, 4/1, 4/2, 5/3/1, 5/3/2, 8-18

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
23 February 2016 (23.02.2016)	11 MAR 2016

Name and mailing address of the ISA/
Mail Stop PCT, Attn: ISA/US, Commissioner for Patents
P.O. Box 1450, Alexandria, Virginia 22313-1450
Facsimile No. 571-273-8300

Authorized officer
Shane Thomas
PCT Helpdesk: 571-272-4300
PCT OSP: 571-272-7774

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US15/51928

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☒ Claims Nos.: 6, 7
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☐ No protest accompanied the payment of additional search fees.