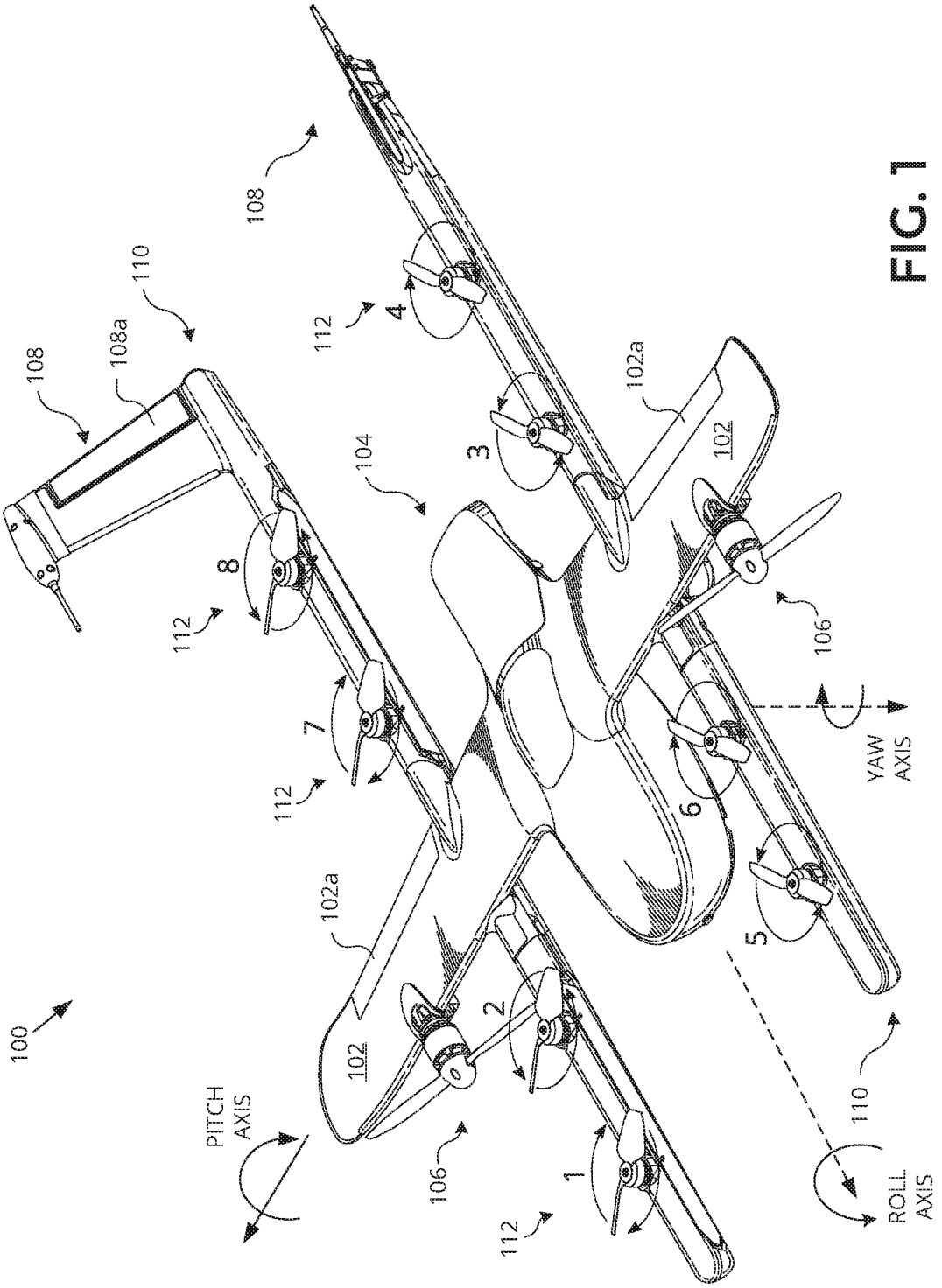

100
108
108a
110
112
102
102a
104
106
PITCH AXIS
YAW AXIS
ROLL AXIS
1
2
3
4
5
6
7
8

FIG. 1

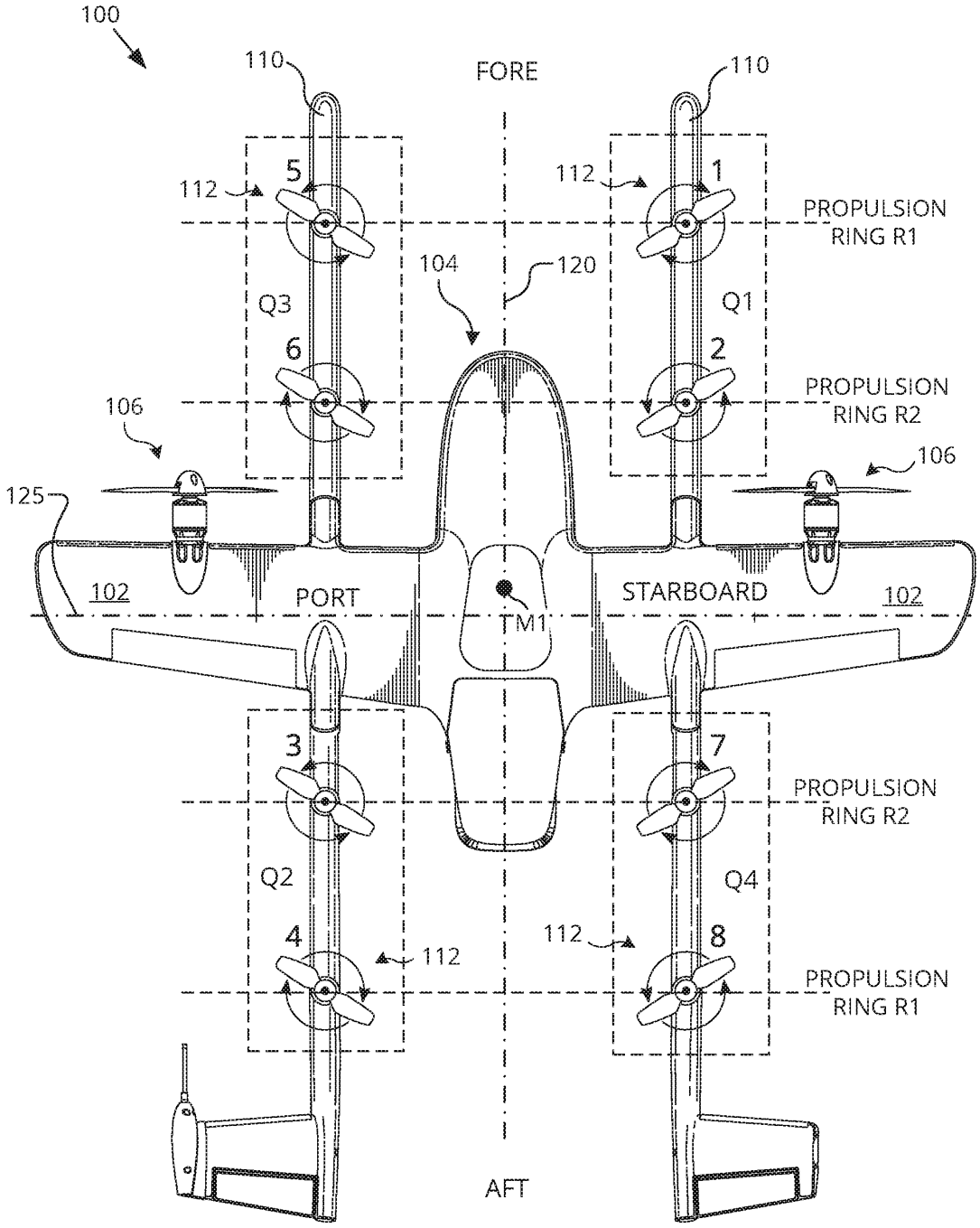

100
110
110
FORE
112
5
112
1
PROPULSION
RING R1
104
120
Q3
Q1
6
2
PROPULSION
RING R2
106
106
125
102
PORT
M1
STARBOARD
102
3
7
PROPULSION
RING R2
Q2
Q4
4
112
112
8
PROPULSION
RING R1
AFT

FIG. 2

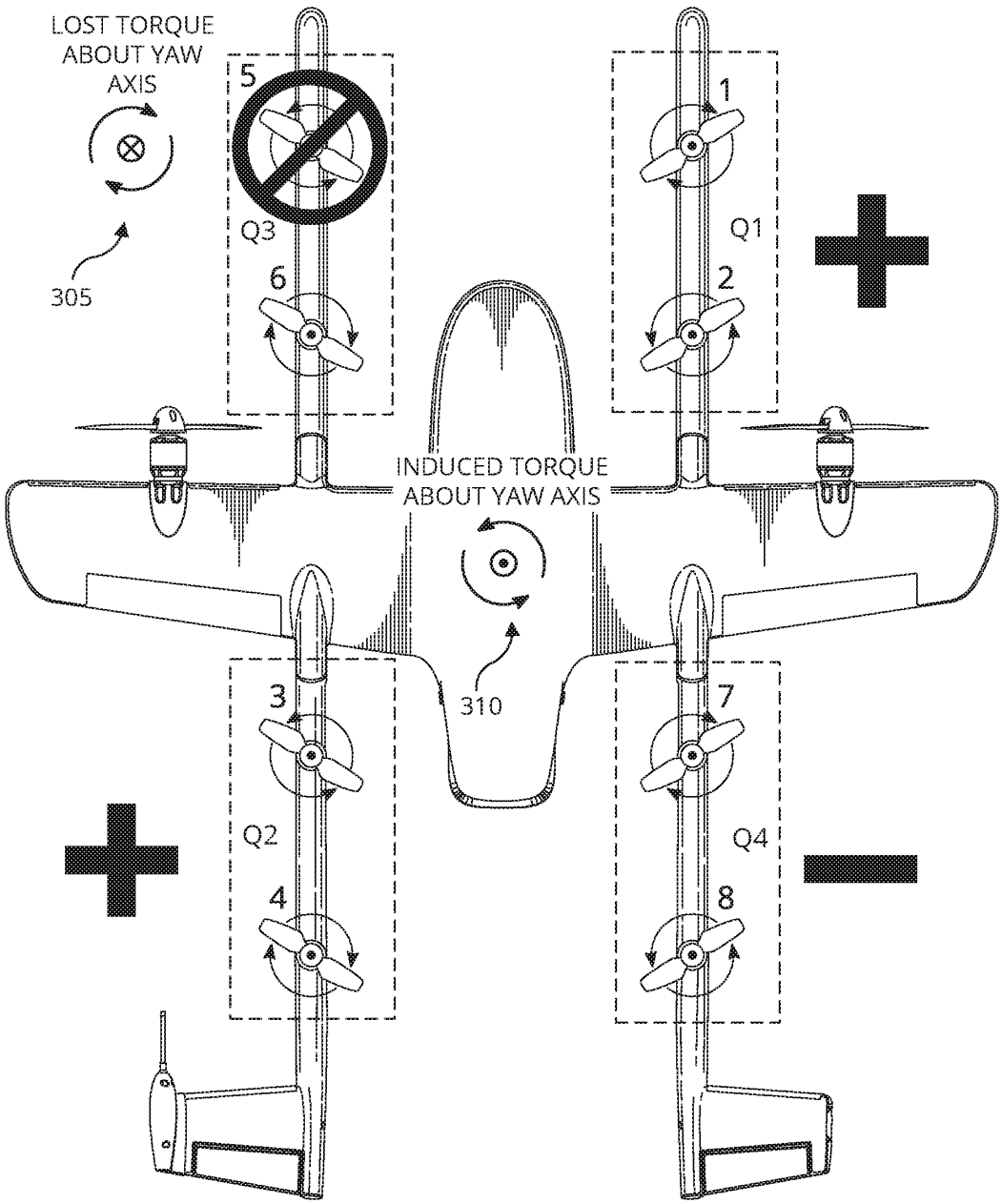

LOST TORQUE
ABOUT YAW
AXIS
305
5
Q3
6
1
Q1
2
INDUCED TORQUE
ABOUT YAW AXIS
310
3
Q2
4
7
Q4
8

FIG. 3

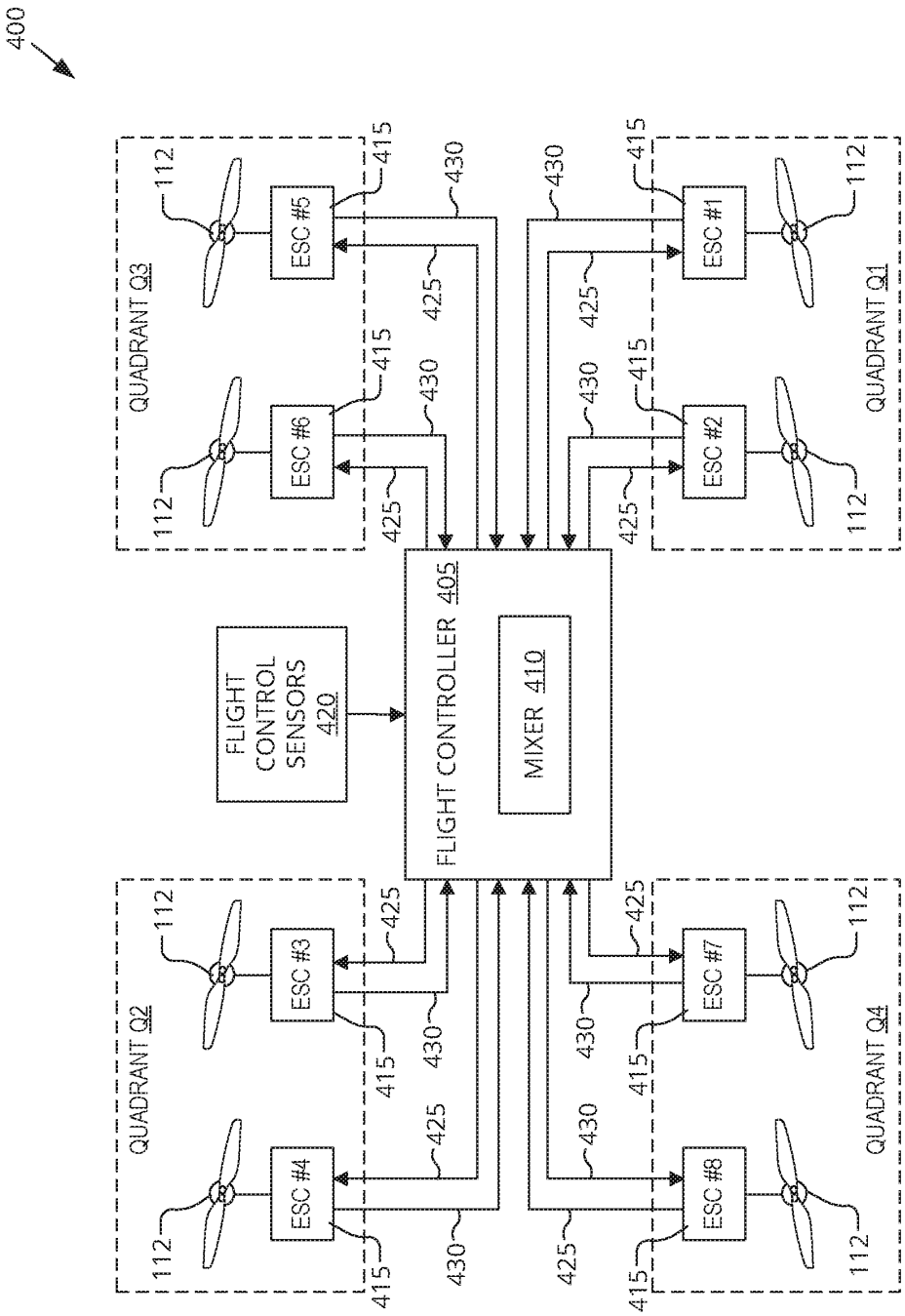
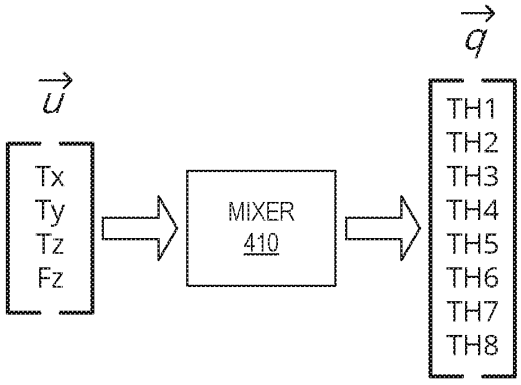

400
QUADRANT Q3
QUADRANT Q1
QUADRANT Q2
QUADRANT Q4
ESC #1
ESC #2
ESC #3
ESC #4
ESC #5
ESC #6
ESC #7
ESC #8
112
415
425
430
FLIGHT CONTROL SENSORS 420
FLIGHT CONTROLLER 405
MIXER 410

FIG. 4



FLIGHT CONTROL EQUATIONS

$$\vec{u} = B\ \vec{q} \quad \text{(Eq1)}$$

$$\vec{q} = B^{+}\ \vec{u} \quad \text{(Eq2)}$$

$\vec{u}$ = Force Cmd Input Vector

$\vec{q}$ = Thrust Cmd Output Vector

B = Control Effectiveness Matrix

B^{+} = Allocation Matrix

$$B = \begin{array}{c} \begin{matrix} C1 & C2 & C3 & C4 & C5 & C6 & C7 & C8 \end{matrix} \\ \begin{bmatrix} X & X & X & X & X & X & X & X \\ X & X & X & X & X & X & X & X \\ X & X & X & X & X & X & X & X \\ X & X & X & X & X & X & X & X \end{bmatrix} \end{array}$$

$$BB^{+} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

505

FIG. 5

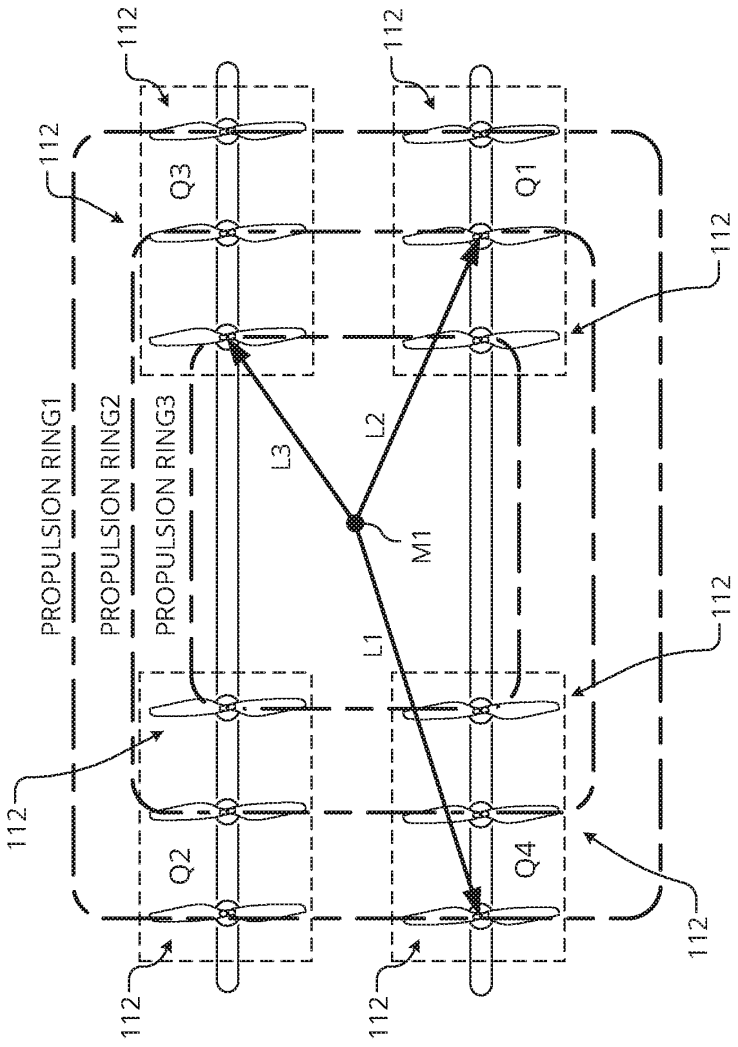

PROPULSION RING1
PROPULSION RING2
PROPULSION RING3
Q1
Q2
Q3
Q4
L1
L2
L3
M1
112

FIG. 6

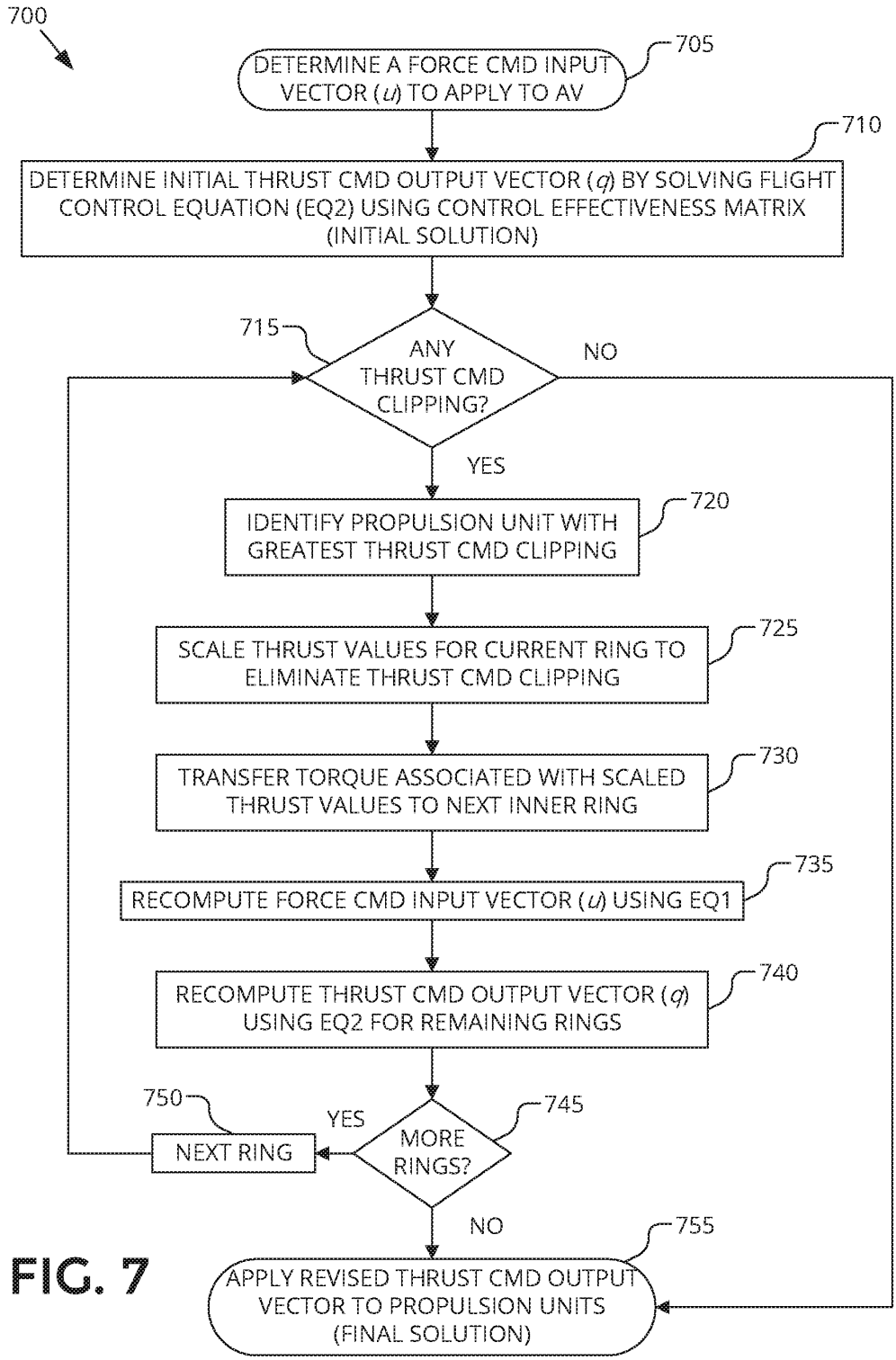

700
DETERMINE A FORCE CMD INPUT VECTOR (u) TO APPLY TO AV
705
DETERMINE INITIAL THRUST CMD OUTPUT VECTOR (q) BY SOLVING FLIGHT CONTROL EQUATION (EQ2) USING CONTROL EFFECTIVENESS MATRIX (INITIAL SOLUTION)
710
715
ANY THRUST CMD CLIPPING?
NO
YES
IDENTIFY PROPULSION UNIT WITH GREATEST THRUST CMD CLIPPING
720
SCALE THRUST VALUES FOR CURRENT RING TO ELIMINATE THRUST CMD CLIPPING
725
TRANSFER TORQUE ASSOCIATED WITH SCALED THRUST VALUES TO NEXT INNER RING
730
RECOMPUTE FORCE CMD INPUT VECTOR (u) USING EQ1
735
RECOMPUTE THRUST CMD OUTPUT VECTOR (q) USING EQ2 FOR REMAINING RINGS
740
750
YES
MORE RINGS?
745
NEXT RING
NO
755
APPLY REVISED THRUST CMD OUTPUT VECTOR TO PROPULSION UNITS (FINAL SOLUTION)

FIG. 7

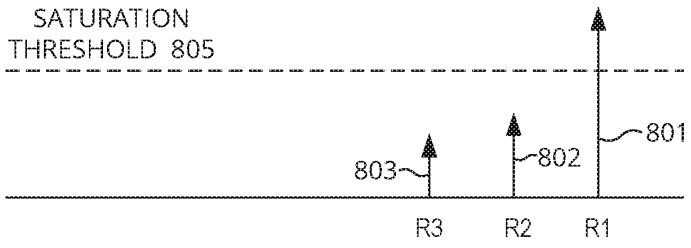


FIG. 8A

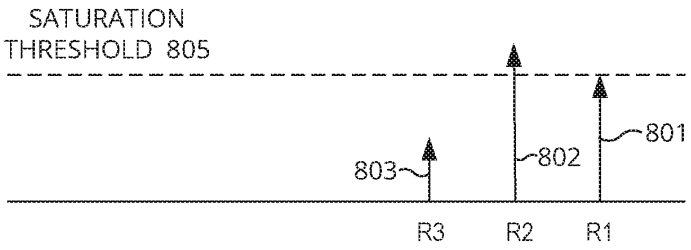


FIG. 8B

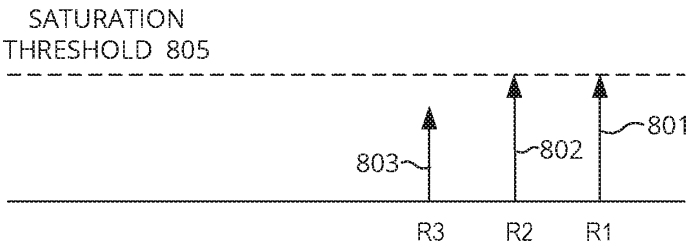


FIG. 8C

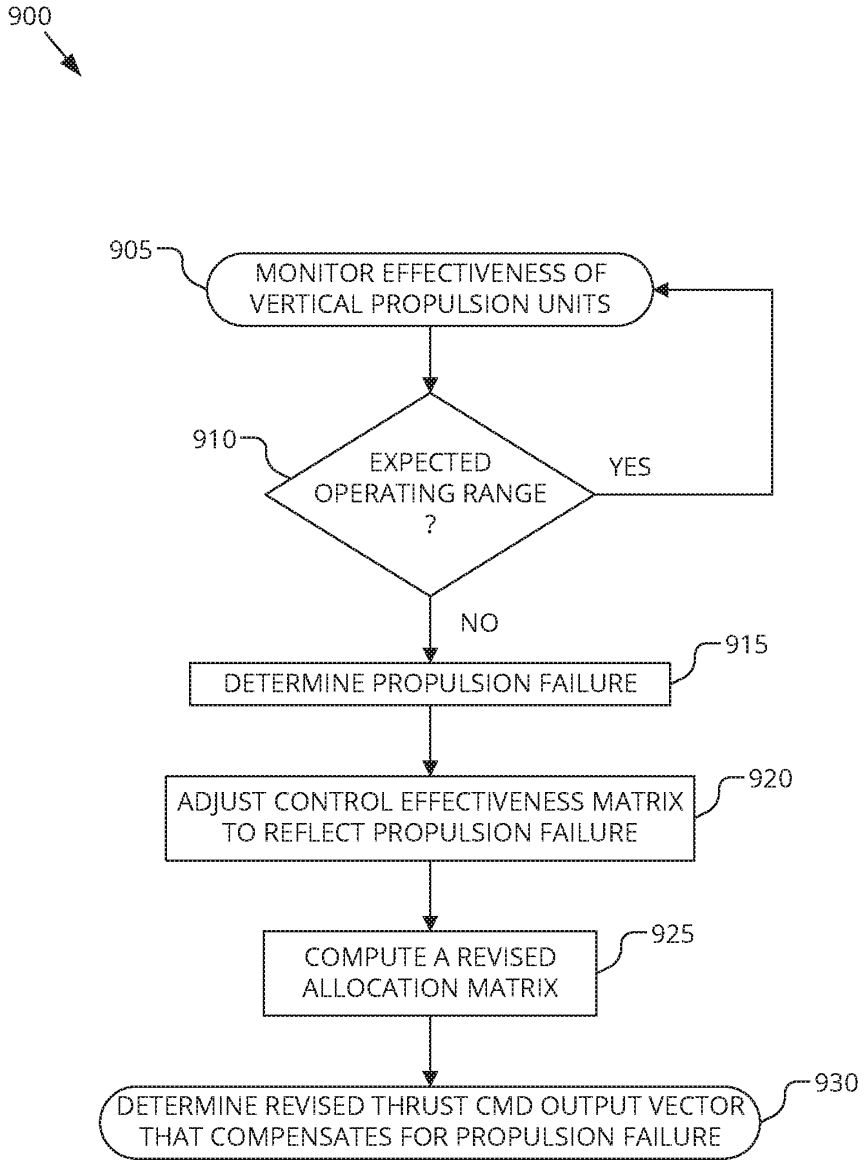

900
905
MONITOR EFFECTIVENESS OF VERTICAL PROPULSION UNITS
910
EXPECTED OPERATING RANGE ?
YES
NO
915
DETERMINE PROPULSION FAILURE
920
ADJUST CONTROL EFFECTIVENESS MATRIX TO REFLECT PROPULSION FAILURE
925
COMPUTE A REVISED ALLOCATION MATRIX
930
DETERMINE REVISED THRUST CMD OUTPUT VECTOR THAT COMPENSATES FOR PROPULSION FAILURE

FIG. 9