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SEA KING MK. 50 HELICOPTER FLIGHT CONTROL SYSTEM

A MATHEMATICAL MODEL OF THE FLYING CONTROLS

by

C. R. GUY

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SUMMARY

A mathematical model for the flying controls of the Sea King Mk.50 helicopter is presented. The operation of the systems and components used in the flying controls of the aircraft is described first, followed by a detailed description of the construction and functioning of the mathematical model. Equations and diagrams for the model are included.

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16. *ABSTRACT*

A mathematical model for the flying controls of the Sea King Mk.50 helicopter is presented. The operation of the systems and components used in the flying controls of the aircraft is described first, followed by a detailed description of the construction and functioning of the mathematical model. Equations and diagrams for the model are included.

CONTENTS

1. INTRODUCTION

The object of this report is to describe a mathematical model of the flying controls used in the Sea King Mk.50 helicopter. This is used in conjunction with a mathematical model representing the automatic flight control system (AFCS—Refs 1 and 2). Together, the flying controls and AFCS form the control systems for the helicopter. The controls system model combines with mathematical models of the aerodynamics/kinematics and sonar cable/transducer to form a complete helicopter/sonar dynamics model. This constitutes a major part of ARL task RD 69/74/4; Aircraft Behaviour Studies—Sea King. An overall block diagram for the helicopter/sonar system is shown in Figure 1.

The flying controls model presented here has many similarities to the flying controls used in the Wessex helicopter mathematical model developed by Packer at Weapons Research Establishment† (Refs 3–6). Block diagrams for these have been included in the ARL version of the Wessex mathematical model (Ref 7) and the programmed form of the control laws has been incorporated in Reference 6. In addition, a simplified form of the Sea King flying controls has been described in Reference 8.

The model presented here makes representations of the elements forming the flying controls used in the aircraft (unlike the model outlined in Reference 8, which represents only the overall control laws). For example, when modelling the cyclic fore-and-aft channel, representations of the trim actuator, cyclic stick, auxiliary and primary servo jacks, mehanical linkages (including the mixing unit) and rotor head are made. Non-linearities resulting from the physical construction of the servos are included, as are stops limiting the travel of the cyclic control stick. Full descriptions of the flying controls used in the aircraft, including the primary and auxiliary servos, are given in References 9–12.

Section 2 of this document describes the operation of the systems and components used in the flying controls of the aircraft. Section 3 outlines the mathematical model; this is subdivided into fore-and-aft cyclic pitch control, lateral cyclic pitch control, collective pitch control and tail rotor control. Block diagrams for the flying controls model are presented (Figs 2 to 5) and the equations describing the model are given in appendix I. An alternative to the collective stick model presented in Section 3.3 is that developed by Packer for the Wessex helicopter mathematical model (Refs 6 and 7) and a description of this is given in Appendix II.

2. THE FLYING CONTROLS OF THE AIRCRAFT

2.1 General operation

The aircraft is controlled by changes in pitch of the main and tail rotor blades which are actuated either by pilot inputs or automatic flight control system (AFCS) inputs. The flying controls connect these inputs to the horns which control rotor blade angular position. Reference 9 describes the flying controls of the aircraft and this section is a summary of that document. Figure 6 is a diagram of the flying controls used in the helicopter.

The pilot's main controls are a cyclic stick which moves both fore-aft and laterally, a collective pitch lever and rudder pedals. The cyclic pitch flying controls function in the natural sense, movement of the control stick producing a corresponding movement in flight through variation in cyclic pitch blade angle. The collective pitch lever controls the ascent and descent of the aircraft by simultaneous variation of the pitch of the main rotor blades and at the same time generates the necessary corrective change in pitch of the tail rotor, known as yaw cross-feed, through the mixing unit. The rudder pedals operate the servo jack and levers which change the pitch of the tail rotor blades to obtain directional control.

† Now Defence Research Centre, Salisbury.

In the aircraft, movement of the cyclic pitch stick and the collective pitch lever is transmitted to the auxiliary servo unit and mixing unit by means of control rods and bell-cranks (see Fig. 6). Control movement then passes via more control rods and mechanisms to the primary servo jacks, which actuate a non-rotating star. Through a swashplate action, displacement of the non-rotating star displaces a rotating star to effect a change of pitch to the blades through push-pull rods connected between the rotating star and the sleeve spindle horns. Until they reach the mixing unit, collective pitch and cyclic pitch movements are independent, but the mixing unit superimposes collective pitch on the cyclic pitch movement and supplies the yaw cross-feed.

Movement of the rudder pedals is transmitted to the mixing unit in a similar manner to the cyclic and collective pitch controls. However, from the mixing unit, control is transferred via cables, push-pull rods and bell-cranks to the tail rotor pitch change mechanism. A yaw force link, which is installed in the tail rotor control run, operates as a control push-pull rod during normal operation of the tail rotor controls, but in the event of the pilot making an over-ride control movement (pedal movement opposing AFCS operation), the force link compresses to actuate microswitches to disengage the AFCS signals. Also incorporated in the yaw channel auxiliary servo unit is a hydraulically operated pedal damper. This prevents rapid operation of the rudder pedals causing too-fast changes of pitch in the tail rotor blades.

2.2 Servo assistance

Servo assistance is provided to the flying controls through two sets of servo jacks. Three primary jacks, described in Reference 11, transmit control movements into changes in cyclic pitch by tilting the non-rotating star in the fore-aft and lateral planes. To provide collective pitch movement, all three jacks operate together. Four auxiliary jacks (fore-aft, lateral, yaw and and collective—see Ref. 12), which are situated in the auxiliary servo unit, transmit control movements into servo assistance to the primary servo jacks and through the directional (yaw) controls into changes of pitch in the tail rotor. Note that the yaw auxiliary jack is the only source of servo assistance for the tail rotor controls. The auxiliary servo unit also translates AFCS signals, via electrically-operated servo valves, into changes in pitch of the main and tail rotor through their respective control runs. In addition, the auxiliary servo unit provides supplementary cyclic pitch control from the beeper trim system. This provides fine adjustment of the cyclic stick through pilot operated trim switches and extension of authority for AFCS signals. In the collective and yaw channels, the authority extension is provided by open-loop spring operation of the auxiliary servos (see Refs 9 and 12).

3. THE FLYING CONTROLS MATHEMATICAL MODEL

3.1 Fore-and-aft cyclic pitch control (Fig. 2)

Figure 2 can be subdivided into the following parts: trim actuator, cyclic stick, auxiliary servo and mechanical linkages, primary servo and mechanical linkages and rotor head. A description of each part is given below:

3.1.1 Trim actuator

The trim actuator, which enables fore-aft beeping of the cyclic stick to occur, comprises the electro-hydraulic valve situated in the fore-and-aft jack of the auxiliary servo unit and its associated circuitry. Switches S FWD† and S AFT are operated by the pilot to manually beep the stick (forward and aft respectively) while S FWD H and S AFT H are actuated by the AFCS to provide automatic extension of authority. The beeping system is activated by closure of switch S PC and is used only during anti-submarine warfare (ASW) mode operation of the AFCS. For forward beeping, switch S FWD NU must be on through combination of S PC and S FWD or S FWD H, thus causing THE TDT to have value CCP1. Beeping aft is similar. THE TDT represents the rate of change of stick angle THE STK.

† Throughout this document, the format for variables is of the type used here. This enables a computer program of the mathematical model to be written without changing variable names.

3.1.2 Cyclic stick

The cyclic stick is modelled using an integrator. If the trim release switch (S TRM REL) is on, THE STK takes the value THE PIL, the pilot's stick angle. This enables (manual) coarse control of the cyclic stick. When S TRM REL is off, beeper operation (fine control) can take place where THE STK is formed through the integration of THE TDT. The limits on stick angular motion ($\pm$EL CP1) are applied to THE STK; the mid-point of THE STK is aligned with the mid-point of the fore-aft cyclic blade pitch angle B1S.

3.1.3 Auxiliary servo and mechanical linkages

Constant CCP10 represents the gearing of the mechanical linkages between THE STK and the auxiliary servo input position, D AX PI. The servo itself is represented by the set of components between D AX PI and D AUX P, the output position; a sketch of a basic jack, taken from Reference 12, is given in Figure 7 and the model may be compared with this. Variable D XB P (Fig. 2) represents the position of points C and C′ (Fig. 7) relative to a point on the jack body and is determined by the ratio CCP2/CCP4 which is equivalent to CB/AB. The constant CCP5 represents the ratio DE/C′D and generates D VLV P, the pilot valve position. Signal D AUTO P, which is the flapper position in the servo valve, also contributes to D VLV P through constant CCP3. The jack output velocity, D AP DT, is determined by the physical characteristics of the pilot valve (pressures, orifice areas, etc) and this is non-linear with respect to D VLV P. A sketch showing the form of this function (FAP) is given in Figure 8. Output position D AUX P is obtained from D AP DT by integration and the feedback arrangement represents the geometry of the differential and pilot valve levers. The limits on jack output position are designated EL CP2.

3.1.4 Primary servo and mechanical linkages

The auxiliary jack output position (D AUX P) is transmitted via the mixing unit and other mechanical linkages to the primary jack input position (D PR PI). The overall gain for this is CCP11. In the mixing unit some collective cross feed is added from D AUX A. The modelling of the primary jack is generally similar to that of the auxiliary jack except that no servo valve exists; a diagram of the primary servo jack is shown in Figure 9.

3.1.5 Rotor head

The variable D XB PP represents the output position of the fore-aft primary jack and this is converted into the cyclic blade pitch angle (B1S) via the rotor head mechanism. The constant CCP12 represents the gearing B1S/D XB PP.

3.2 Lateral cyclic pitch control (Fig. 3)

Similar to the fore-and-aft cyclic pitch control model.

3.3 Collective pitch control (Fig. 4)

This is similar to both fore-aft and lateral cyclic pitch models, except that:

(i) The auxiliary jack has an open-loop spring incorporated in it to enable extension of authority for the AFCS. When a large AFCS demand signal (D AUTO A) is applied to the auxiliary servo, D XB A may exceed the open-loop spring compression limit EL CA4. This gives rise to a non-zero value of TH CS D which causes movement of the stick to occur, provided the friction lock (S FRIC) is off or the pilot is not overriding stick movement (SC PIL is off).

The process used in the model to generate stick movement (i.e. the generation of TH CS D from movement D DEAD A) is a simplification of the true behaviour of the collective stick, where a torque is applied when D XB A exceeds EL CA4. This torque gives rise to stick movement provided the above conditions are again obeyed. A collective stick model simulating this behaviour more closely is described in appendix II. However, for general use, the version described above is considered adequate.

(ii) No cross-feed to the collective channel occurs in the mixing unit.

(iii) The terms THEC MD and THC LAG are incorporated in the rotor head model. THEC MD is the mid-value of collective blade pitch angle, THETA C and the THC LAG term represents hinge pitch-lag coupling which reduces blade pitch angle as lagging motion occurs.

(iv) Stick position (THEC ST) is measured relative to its full down position in this channel. In the pitch and roll channels, zero stick angle corresponds to the mid-point of cyclic stick travel in each plane.

(v) There is a non-linear relationship between collective blade pitch angle (THETA C) and stick angle (THEC ST) in this channel because of the open-loop spring action in the auxiliary servo. In the model, this is achieved through the values used for EL CA1–4.

3.4 Tail rotor control (Fig. 5)

This is similar to the collective pitch control model, except that:

(i) S PEDLS represents a yaw force link switch which is on when the pilot applies pedal-force and off when he removes foot pressure; the link enables the pilot to override the AFCS. In addition, the rate of change of pedal movement is limited by a pedal damper. This is incorporated in the model as constant CCY1.

(ii) No primary jack exists in the tail rotor controls. The gearing between the auxiliary jack output position (D AUX Y) and the tail rotor collective blade pitch angle (THETA T) is represented by constant CCY7. An offset term (TH CT MD) is included together with limits on THETA T of EL CY4.

(iii) The collective to yaw cross-feed term (D AUX A multiplied by CCY8) is included in the mixing unit.

(iv) No equivalent of the hinge pitch-lag coupling term (THC LAG) exists.

(v) In this channel, pedal movement can take place due to collective stick movement when the pedals are in an extreme position and the tail rotor pitch limit is reached. In addition, if the tail rotor pitch limit is reached with the yaw pedals not at full travel, further pedal movement in the applied direction can only be achieved if collective pitch is first reduced. To model this behaviour, the circuitry illustrated in Figure 10 is used to set the switches S YFB1, S YFB2 and S D PED shown in Figure 5.

4. CONCLUDING REMARKS

A detailed mathematical model of the flying controls for the Sea King Mk.50 helicopter has been outlined. This is to be used in conjunction with a similarly detailed model of the automatic flight control system to form the complete control systems model. Representations of the elements used in the aircraft's flying controls have been made, including non-linearities. The amount of detail included in the model makes it useful for analysing problems which may arise in service with the control system of the helicopter.

NOMENCLATURE

AIS, BIS	Cyclic blade pitch angles (lateral and fore-aft respectively)
BIAS SP	Bias spring position.
CCA1, ... 15 CCP1, ... 12 CCR1, ... 12 CCY1, ... 11	Constants
D AA DT, D AP DT, D AR DT, D AY DT	Auxiliary servo output velocity
D AUTO A, ... P, ... R, ... Y	AFCS output signal
D AUX A, ... P, ... R, ... Y	Auxiliary servo output position
D AUX AO, ... PO, ... RO, ... YO	Auxiliary servo output position initial condition
D AX AI, ... PI, ... RI, ... YI	Auxiliary servo input position
D AY FB	Yaw auxiliary servo feedback position
D DEAD A, D DEAD Y	Auxiliary servo feedback position due to open loop spring mechanism
DL TH CS	Collective stick angle relative to middle of range of travel
D PA DT, D PP DT, D PR DT	Primary servo output velocity
D PED DT	Rudder pedals integrator input variable
D PEDLS	Rudder pedals position
D PIL Y	Pilot's rudder pedals position
D PR AI, ... PI, ... RI	Primary servo input position
D VLV A, ... P, ... R, ... Y	Auxiliary servo pilot valve position
D VLV PA, ... PP, ... PR	Primary servo pilot valve position
D XB A, ... P, ... R, ... Y	Auxiliary servo pilot valve lever position
D XB PA, ... PP, ... PR	Primary servo output position
D XB PAO, ... PPO, ... PRO	Primary servo output position initial condition

D XSTK	Collective stick cross-bar displacement
D YFB1, ... 2	Yaw auxiliary servo feedback quantities
EL CA1 . . . . 5, EL CP1 . . . . 3, EL CR1 . . . . 3, EL CY1 . . . . 6 EL MAX, EL MIN	Limits
FAC, FAP, FAR, FAY	Auxiliary servo pilot valve characteristic
FPC, FPP, FPR	Primary servo pilot valve characteristic
PHI PIL THE PIL	Pilot's cyclic stick angles
PHI STK THE STK	Cyclic stick angles
PHI TDT THE TDT	Cyclic stick angular velocity
S AFT, S AFT H, S AFT NU	Aft motion beeping switches
SC PIL	Collective stick motion switch
SC ST1, ... 9	Collective stick logic switches
S D PED	Pedals hold switch
S FRIC	Collective stick friction switch
S FWD, S FWD H, S FWD NU	Forward motion beeping switches
S PC S RC	AFCS ASW mode switches
S PEDLS	Yaw force link switch
S PIL A	Stick friction release switch
S PORT, S PORT H, S PORT N	Port motion beeping switches
S STBD, S STBD H, S STBD N	Starboard motion beeping switches
S TRM REL	Cyclic stick trim release switch
S YFB1, ... 2	Pedal movement switches
T ACCN	Collective stick torque due to gravity and airframe motion
TCS D PL	Pilot's collective stick angular velocity
T CS PL	Pilot's collective stick angle
T EX	External torque acting on collective stick
T FRIC	Collective stick frictional torque
THC LAG	Pitch-lag coupling for main rotor
TH CS D	Collective stick integrator input variable
TH CS DD	Collective stick angular acceleration

TH CS DP	Collective stick angular velocity
THC SET THD SET	} Collective stick angle limitations
TH CT MD THEC MD	} Mid-points of tail and main rotor collective pitch angles respectively
TH CS MD	Mid-point of collective stick angle
THEC ST	Collective stick angle
THETA C THETA T	} Main and tail rotor collective blade pitch angles respectively
THE TU	Unlimited tail rotor collective blade pitch angle
T SPRING	Torque due to bias spring on collective stick
T TOT	Total torque acting on collective stick

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9. —	A.P.(RAN)300–1–4.1 Chapter 19. Flying Controls.
10. —	A.P.(RAN)300–1–4.1 Chapter 21–0. Hydraulic Power System —General
11. —	A.P.(RAN)300–1–4.1 Chapter 21–1. Primary System.
12. —	A.P.(RAN)300–1–4.1 Chapter 21–2. Auxiliary System.

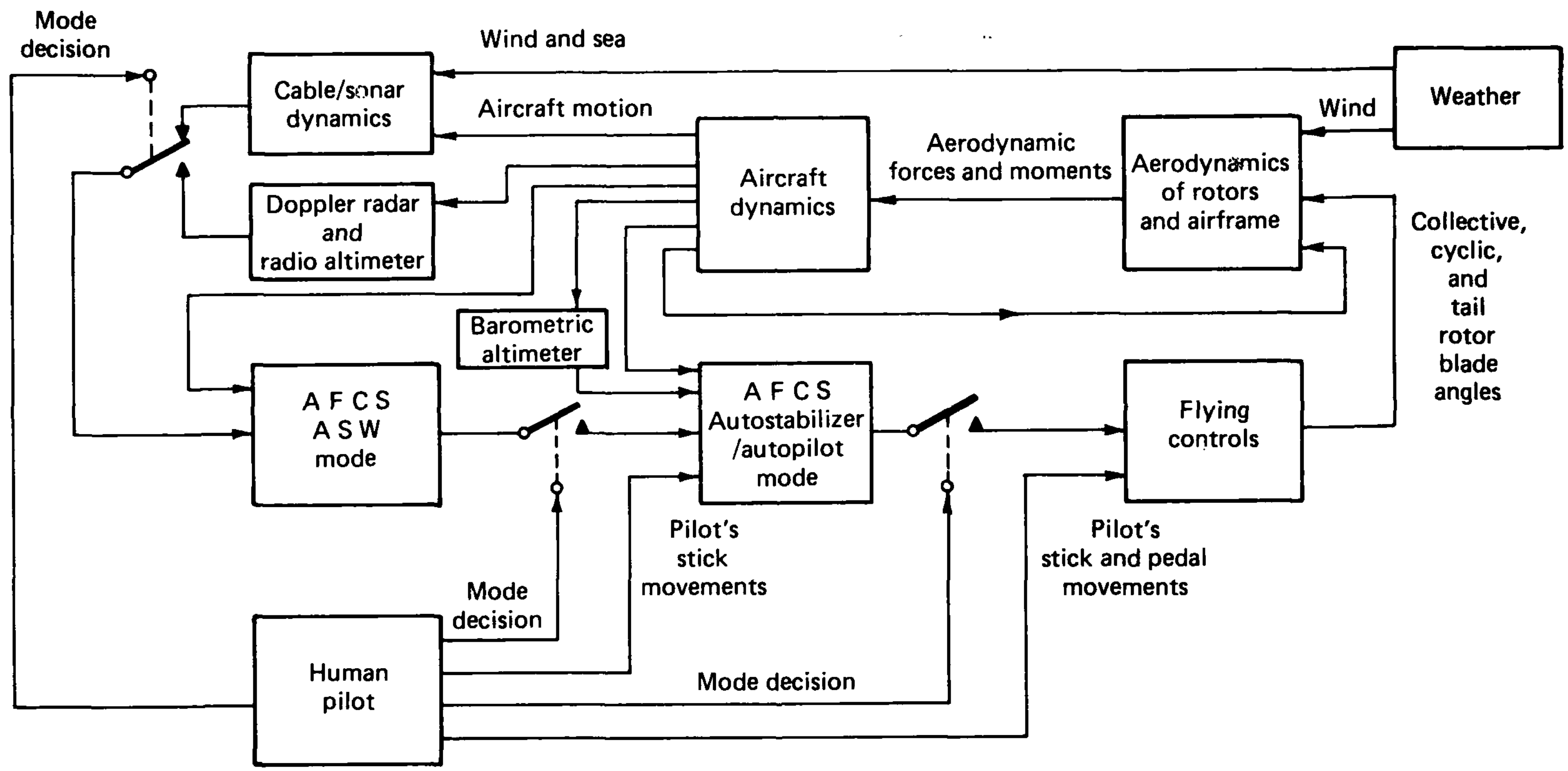

FIG 1. OVERALL BLOCK DIAGRAM FOR THE HELICOPTER/SONAR SYSTEM

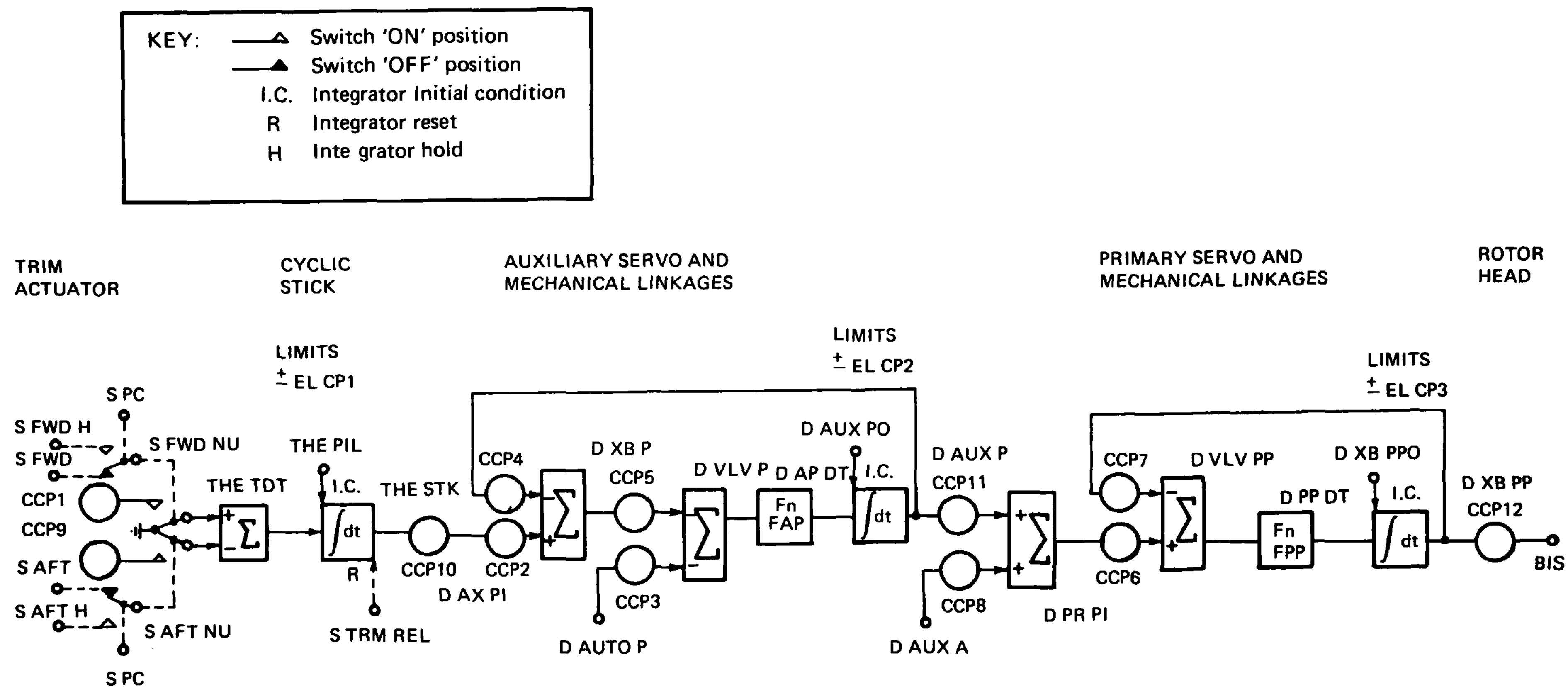

FIG 2. FLYING CONTROLS MODEL; FORE-AND-AFT CYCLIC PITCH CONTROL

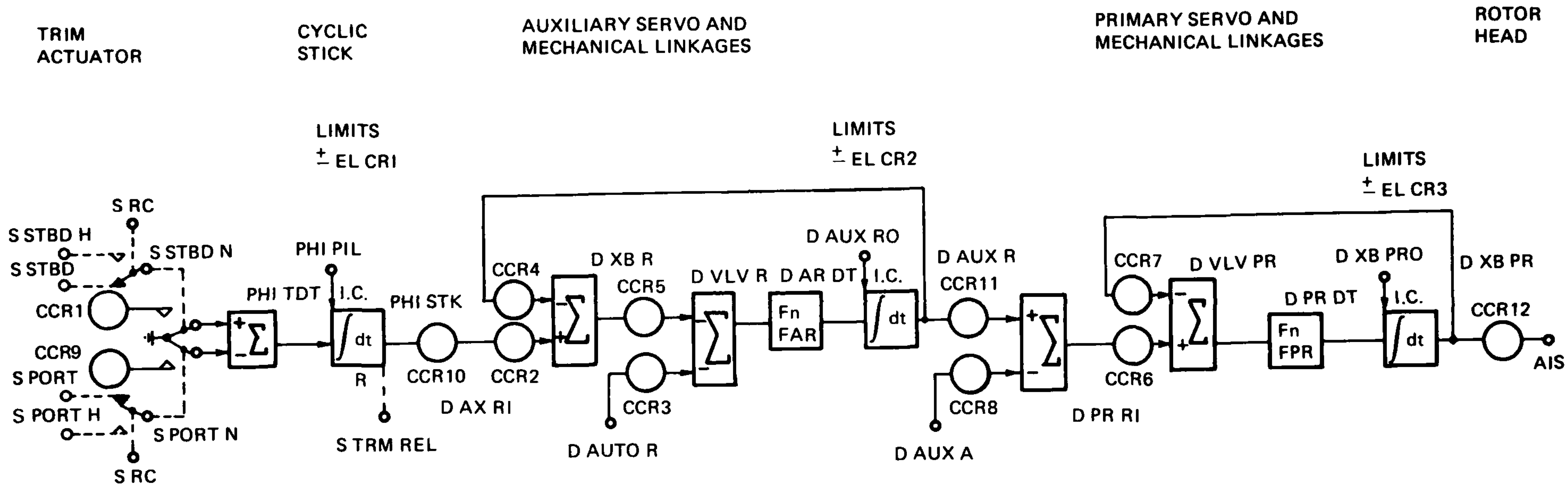

FIG 3. FLYING CONTROLS MODEL; LATERAL CYCLIC PITCH CONTROL

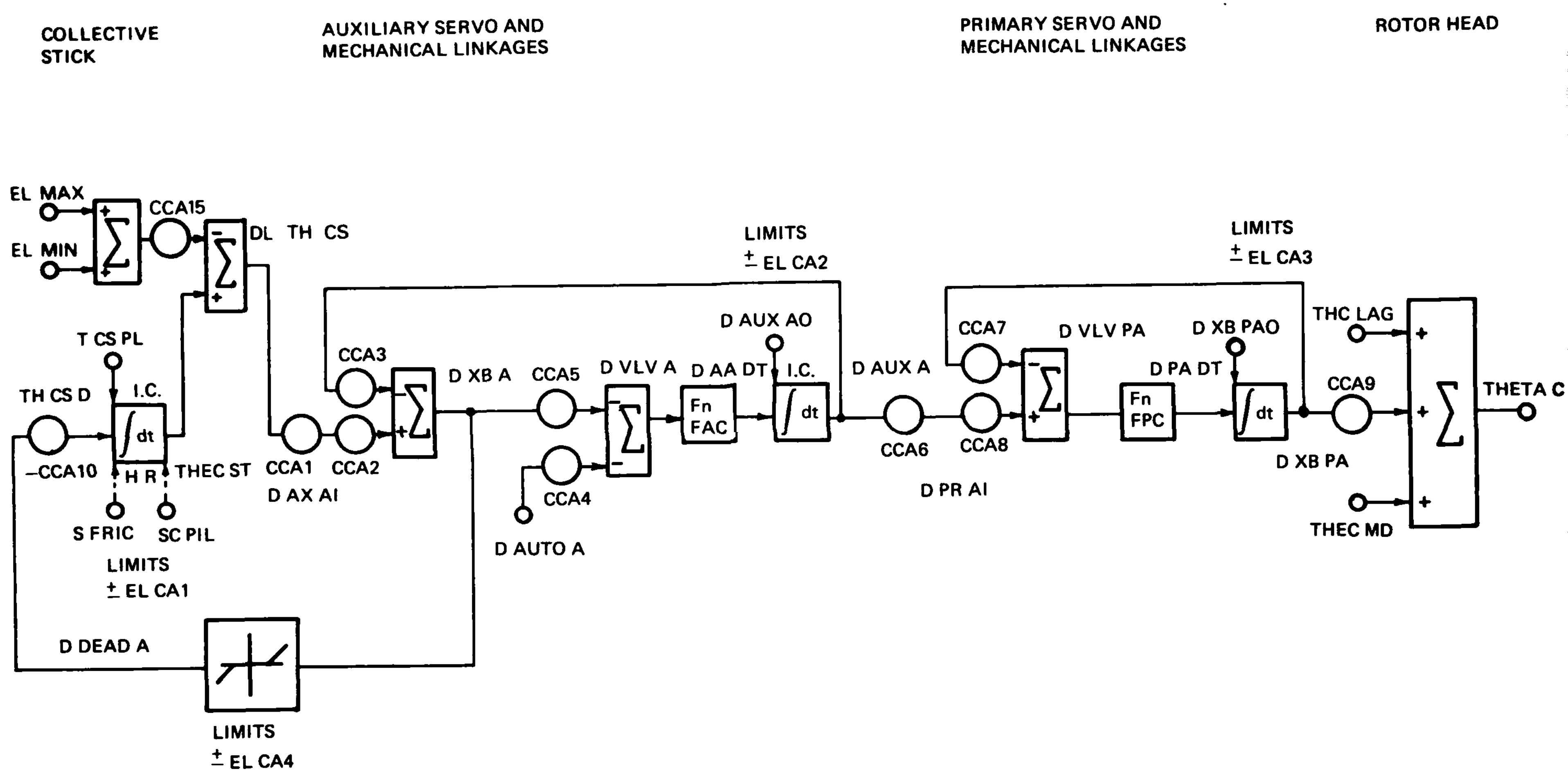

FIG 4. FLYING CONTROLS MODEL; COLLECTIVE PITCH CONTROL

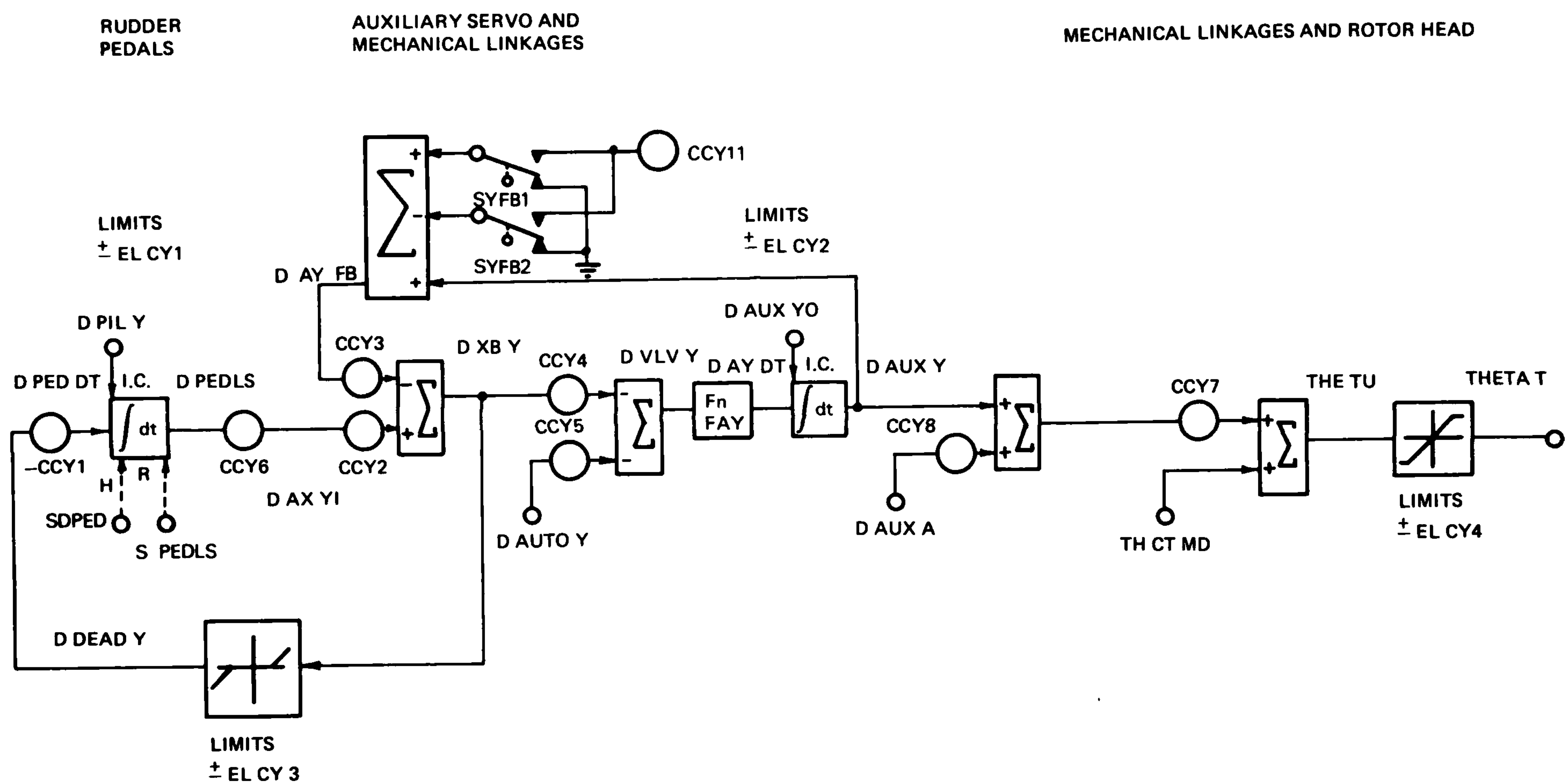

FIG 5. FLYING CONTROLS MODEL; TAIL ROTOR CONTROL

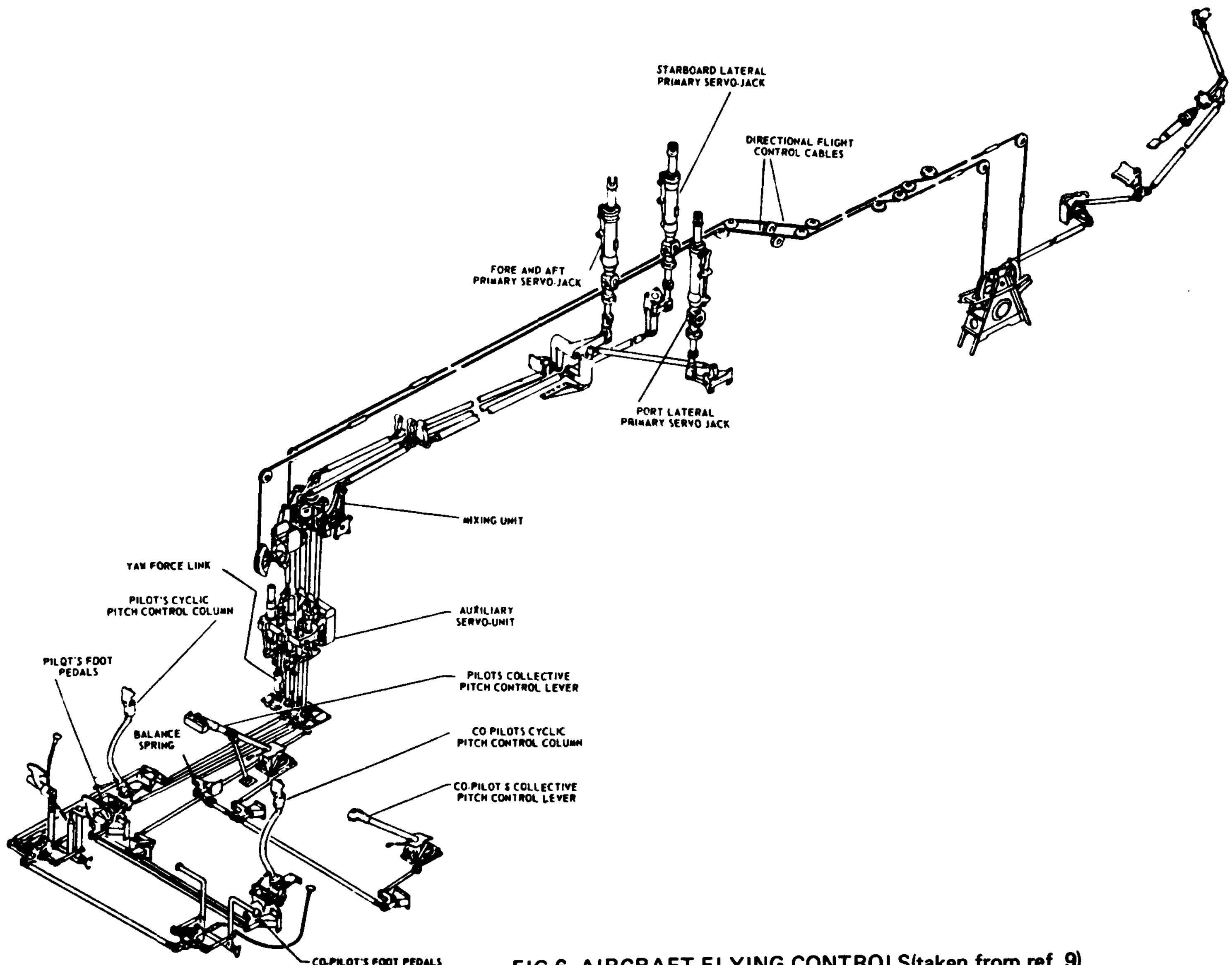

FIG 6. AIRCRAFT FLYING CONTROLS(taken from ref. 9)

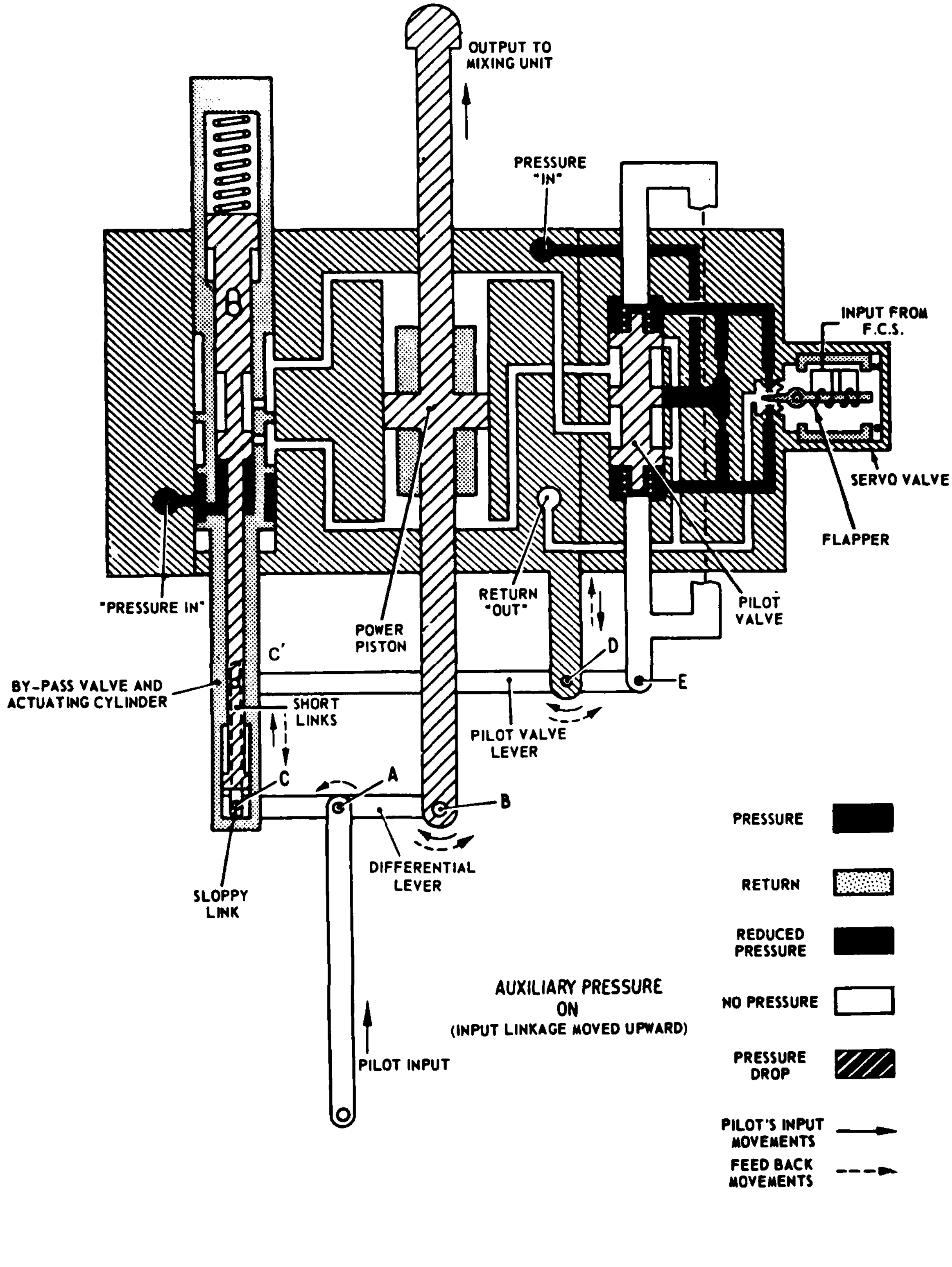

FIG 7. BASIC AUXILIARY JACK (taken from ref. 12)

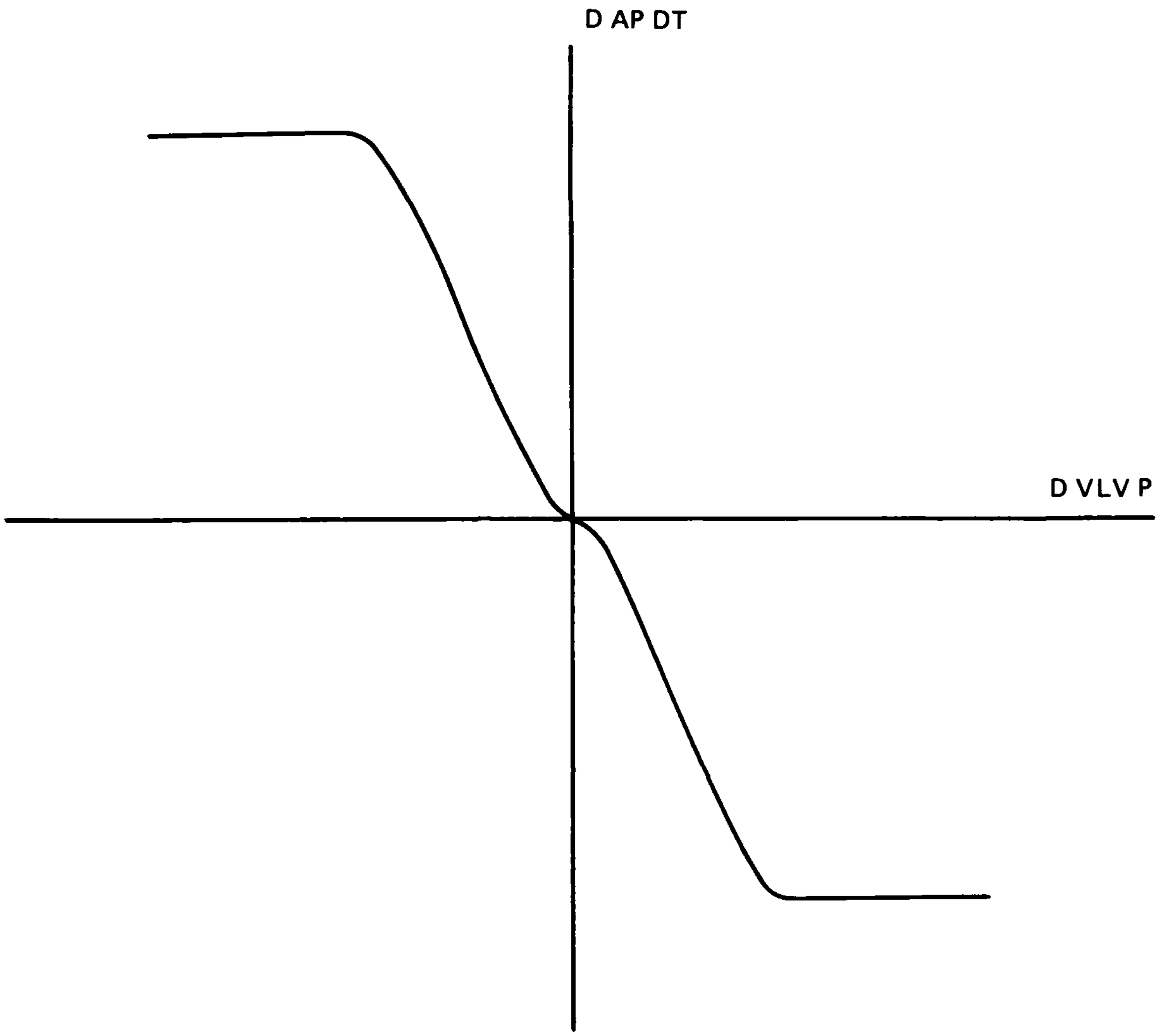

FIG 8. FORM OF FUNCTION FAP

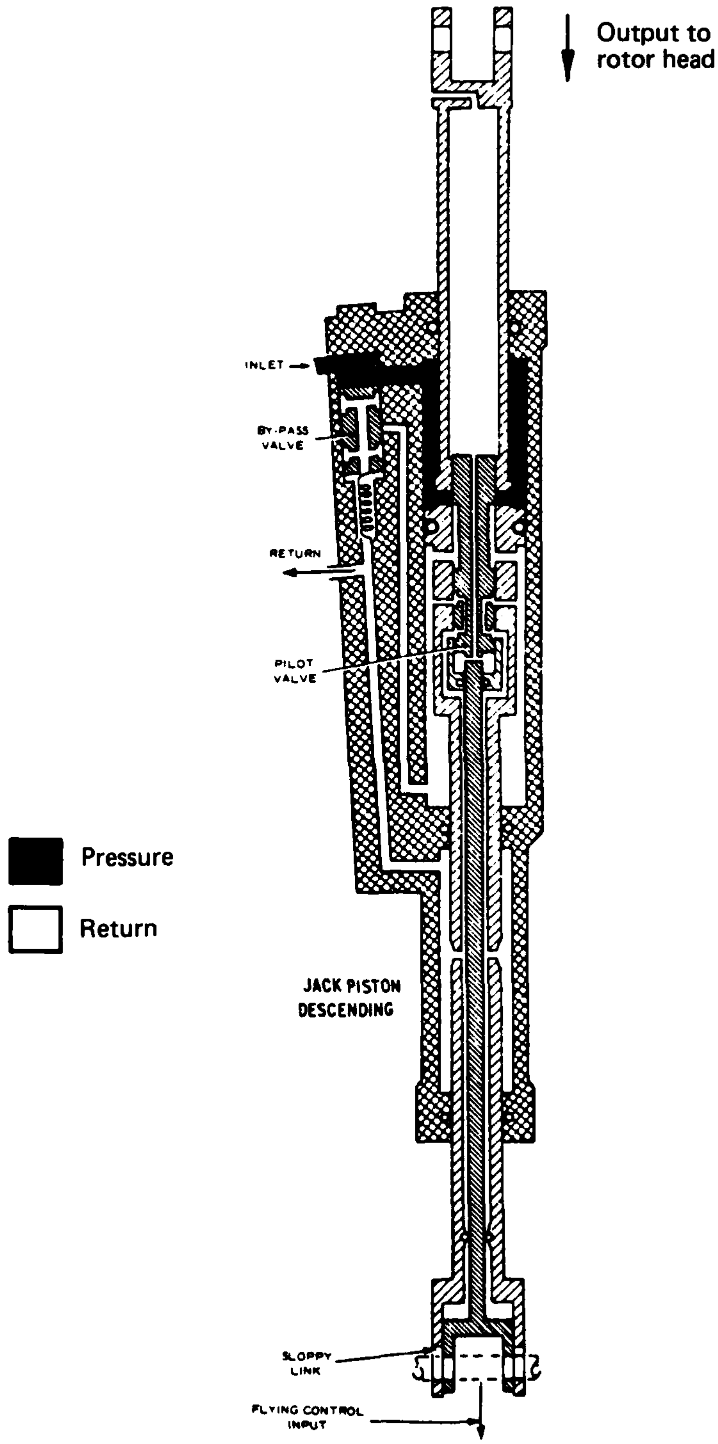

FIG 9. PRIMARY SERVO JACK (taken from ref. 11)

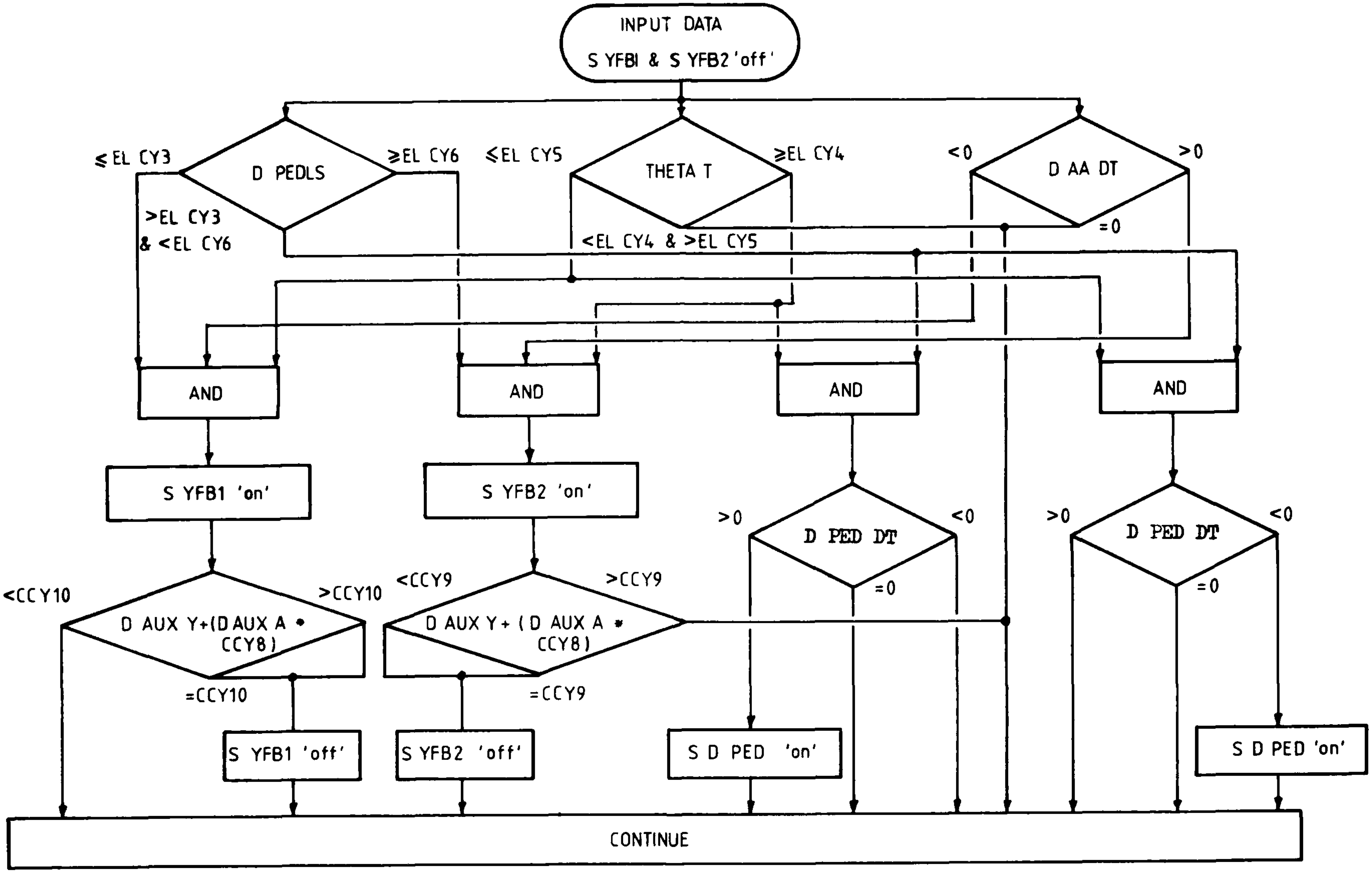

FIG.10 YAW PEDAL MOVEMENT DUE TO COLLECTIVE CROSS-COUPLING

APPENDIX I: EQUATIONS FOR THE FLYING CONTROLS

1. FORE-AND-AFT CYCLIC PITCH CONTROL (Fig. 2)

1.1 Trim actuator

If S PC is off
S FWD NU = S FWD and
S AFT NU = S AFT (1.1)

If S PC is on
S FWD NU = S FWD H and
S AFT NU = S AFT H (1.2)

If S FWD NU is off
THE TDT = O (1.3)

If S FWD NU is on
THE TDT = CCP1 (1.4)

If S AFT NU is off
THE TDT = O (1.5)

If S AFT NU is on
THE TDT = −CCP9 (1.6)

1.2 Cyclic stick

If S TRM REL is off
THE STK = ∫(THE TDT) dt (1.7)

If S TRM REL is on
THE STK = THE PIL (1.8)

If |THE STK| < |EL CP1|
THE STK = THE STK (1.9)

If |THE STK| ⩾ |EL CP1|
THE STK = |EL CP1| * SIGN THE STK (1.10)

1.3 Auxiliary servo and mechanical linkages

D AX PI = CCP10 * THE STK (1.11)

D XB P = (CCP2 * D AX PI) − (CCP4 * D AUX P) (1.12)

D VLV P = −(CCP5 * D XB P) − (CCP3 * D AUTO P) (1.13)

D AP DT = Function (D VLV P) (1.14)

D AUX P = ∫ (D AP DT) dt (1.15)

If |D AUX P| < |EL CP2|
D AUX P = D AUX P (1.16)

If |D AUX P| ⩾ |EL CP2|
D AUX P = |EL CP2| * SIGN D AUX P (1.17)

1.4 Primary servo and mechanical linkages

D PR PI = (CCP11 * D AUX P) + (CCP8 * D AUX A) (1.18)

D VLV PP = (CCP6 * D PR PI) − (CCP7 * D XB PP) (1.19)

D PP DT = Function (D VLV PP) (1.20)

D XB PP = ∫ (D PP DT) dt (1.21)

If |D XB PP| < |EL CP3|
D XB PP = D XB PP } (1.22)

If |D XB PP| ≥ |EL CP3|
D XB PP = |EL CP3| * SIGN D XB PP } (1.23)

1.5 Rotor head

B1S = CCP12 * D XB PP (1.24)

2. LATERAL CYCLIC PITCH CONTROL (Fig. 3)

2.1 Trim actuator

If S RC is off
S STBD N = S STBD and
S PORT N = S PORT } (2.1)

If S RC is on
S STBD N = S STBD H and
S PORT N = S PORT H } (2.2)

If S STBD N is off
PHI TDT = O } (2.3)

If S STBD N is on
PHI TDT = CCR1 } (2.4)

If S PORT N is off
PHI TDT = O } (2.5)

If S PORT N is on
PHI TDT = −CCR9 } (2.6)

2.2 Cyclic stick

If S TRM REL is off
PHI STK = ∫ (PHI TDT) dt } (2.7)

If S TRM REL is on
PHI STK = PHI PIL } (2.8)

If |PHI STK| < |EL CR1|
PHI STK = PHI STK } (2.9)

If |PHI STK| ≥ |EL CR1|
PHI STK = |EL CR1| * SIGN PHI STK } (2.10)

2.3 Auxiliary servo and mechanical linkages

D AX RI = CCR10 * PHI STK (2.11)

D XB R = (CCR2 * D AX RI) − (CCR4 * D AUX R) (2.12)

$$\mathrm{D\ VLV\ R} = -(\mathrm{CCR5} * \mathrm{D\ XB\ R}) - (\mathrm{CCR3} * \mathrm{D\ AUTO\ R}) \tag{2.13}$$

$$\mathrm{D\ AR\ DT} = \text{Function } (\mathrm{D\ VLV\ R}) \tag{2.14}$$

$$\mathrm{D\ AUX\ R} = \int (\mathrm{D\ AR\ DT})\, dt \tag{2.15}$$

$$\left.\begin{aligned}&\text{If } |\mathrm{D\ AUX\ R}| < |\mathrm{EL\ CR2}|\\ &\mathrm{D\ AUX\ R} = \mathrm{D\ AUX\ R}\end{aligned}\right\} \tag{2.16}$$

$$\left.\begin{aligned}&\text{If } |\mathrm{D\ AUX\ R}| \geqslant |\mathrm{EL\ CR2}|\\ &\mathrm{D\ AUX\ R} = |\mathrm{EL\ CR2}| * \mathrm{SIGN\ D\ AUX\ R}\end{aligned}\right\} \tag{2.17}$$

2.4 Primary servo and mechanical linkages

$$\mathrm{D\ PR\ RI} = (\mathrm{CCR11} * \mathrm{D\ AUX\ R}) - (\mathrm{CCR8} * \mathrm{D\ AUX\ A}) \tag{2.18}$$

$$\mathrm{D\ VLV\ PR} = (\mathrm{CCR6} * \mathrm{D\ PR\ RI}) - (\mathrm{CCR7} * \mathrm{D\ XB\ PR}) \tag{2.19}$$

$$\mathrm{D\ PR\ DT} = \text{Function } (\mathrm{D\ VLV\ PR}) \tag{2.20}$$

$$\mathrm{D\ XB\ PR} = \int (\mathrm{D\ PR\ DT})\, dt \tag{2.21}$$

$$\left.\begin{aligned}&\text{If } |\mathrm{D\ XB\ PR}| < |\mathrm{EL\ CR3}|\\ &\mathrm{D\ XB\ PR} = \mathrm{D\ XB\ PR}\end{aligned}\right\} \tag{2.22}$$

$$\left.\begin{aligned}&\text{If } |\mathrm{D\ XB\ PR}| \geqslant |\mathrm{EL\ CR3}|\\ &\mathrm{D\ XB\ PR} = |\mathrm{EL\ CR3}| * \mathrm{SIGN\ D\ XB\ PR}\end{aligned}\right\} \tag{2.23}$$

2.5 Rotor head

$$\mathrm{A1S} = \mathrm{CCR12} * \mathrm{D\ XB\ PR} \tag{2.24}$$

3. COLLECTIVE PITCH CONTROL (Fig. 4)

3.1 Collective stick

$$\mathrm{TH\ CS\ D} = -\mathrm{CCA10} * \mathrm{D\ DEAD\ A} \tag{3.1}$$

$$\left.\begin{aligned}&\text{If SC PIL is off}\\ &\mathrm{THEC\ ST} = \int (\mathrm{TH\ CS\ D})\, dt\end{aligned}\right\} \tag{3.2}$$

$$\left.\begin{aligned}&\text{If SC PIL is on}\\ &\mathrm{THEC\ ST} = \mathrm{T\ CS\ PL}\end{aligned}\right\} \tag{3.3}$$

$$\left.\begin{aligned}&\text{If S FRIC is off}\\ &\mathrm{THEC\ ST} = \mathrm{THEC\ ST}\end{aligned}\right\} \tag{3.4}$$

$$\left.\begin{aligned}&\text{If S FRIC is on}\\ &\mathrm{THEC\ ST} = \text{THEC ST at time when S FRIC engaged}\end{aligned}\right\} \tag{3.5}$$

$$\left.\begin{aligned}&\text{If } |\mathrm{THEC\ ST}| < |\mathrm{EL\ CA1}|\\ &\mathrm{THEC\ ST} = \mathrm{THEC\ ST}\end{aligned}\right\} \tag{3.6}$$

$$\left.\begin{aligned}&\text{If } |\mathrm{THEC\ ST}| \geqslant |\mathrm{EL\ CA1}|\\ &\mathrm{THEC\ ST} = |\mathrm{EL\ CA1}| * \mathrm{SIGN\ THEC\ ST}\end{aligned}\right\} \tag{3.7}$$

$$\mathrm{DL\ TH\ CS} = \mathrm{THEC\ ST} - \mathrm{CCA11} * (\mathrm{EL\ MAX} + \mathrm{EL\ MIN}) \tag{3.8}$$

3.2 Auxiliary servo and mechanical linkages

$$\mathrm{D\ AX\ AI} = \mathrm{CCA1} * \mathrm{DL\ TH\ CS} \tag{3.9}$$

$$\mathrm{D\ XB\ A} = (\mathrm{CCA2} * \mathrm{D\ AX\ AI}) - (\mathrm{CCA3} * \mathrm{D\ AUX\ A}) \tag{3.10}$$

$$\mathrm{D\ VLV\ A} = -(\mathrm{CCA5} * \mathrm{D\ XB\ A}) - (\mathrm{CCA4} * \mathrm{D\ AUTO\ A}) \tag{3.11}$$

$$\mathrm{D\ AA\ DT} = \text{Function } (\mathrm{D\ VLV\ A}) \tag{3.12}$$

$$D\ AUX\ A = \int (D\ AA\ DT)\,dt \tag{3.13}$$

$$\left.\begin{array}{l}\text{If } |D\ AUX\ A| < |EL\ CA2| \\ D\ AUX\ A = D\ AUX\ A\end{array}\right\} \tag{3.14}$$

$$\left.\begin{array}{l}\text{If } |D\ AUX\ A| \geqslant |EL\ CA2| \\ D\ AUX\ A = |EL\ CA2| * SIGN\ D\ AUX\ A\end{array}\right\} \tag{3.15}$$

$$\left.\begin{array}{l}\text{If } |D\ XB\ A| < |EL\ CA4| \\ D\ DEAD\ A = O\end{array}\right\} \tag{3.16}$$

$$\left.\begin{array}{l}\text{If } |D\ XB\ A| \geqslant |EL\ CA4| \\ D\ DEAD\ A = (|D\ XB\ A| - |EL\ CA4|) * SIGN\ D\ XB\ A\end{array}\right\} \tag{3.17}$$

3.3 Primary servo and mechanical linkages

$$D\ PR\ AI = CCA6 * D\ AUX\ A \tag{3.18}$$

$$D\ VLV\ PA = (CCA8 * D\ PR\ AI) - (CCA7 * D\ XB\ PA) \tag{3.19}$$

$$D\ PA\ DT = \text{Function}\ (D\ VLV\ PA) \tag{3.20}$$

$$D\ XB\ PA = \int (D\ PA\ DT)\,dt \tag{3.21}$$

$$\left.\begin{array}{l}\text{If } |D\ XB\ PA| < |EL\ CA3| \\ D\ XB\ PA = D\ XB\ PA\end{array}\right\} \tag{3.22}$$

$$\left.\begin{array}{l}\text{If } |D\ XB\ PA| \geqslant |EL\ CA3| \\ D\ XB\ PA = |EL\ CA3| * SIGN\ D\ XB\ PA\end{array}\right\} \tag{3.23}$$

3.4 Rotor head

$$THETA\ C = (CCA9 * D\ XB\ PA) + (THC\ LAG) + (THEC\ MD) \tag{3.24}$$

4. TAIL ROTOR CONTROL (Fig. 5)

4.1 Rudder pedals

$$D\ PED\ DT = -CCYI * D\ DEAD\ Y \tag{4.1}$$

$$\left.\begin{array}{l}\text{If S PEDLS is off} \\ D\ PEDLS = \int (D\ PED\ DT)\,dt\end{array}\right\} \tag{4.2}$$

$$\left.\begin{array}{l}\text{If S PEDLS is on} \\ D\ PEDLS = D\ PIL\ Y\end{array}\right\} \tag{4.3}$$

$$\left.\begin{array}{l}\text{If } |D\ PEDLS| < |EL\ CY1| \\ D\ PEDLS = D\ PEDLS\end{array}\right\} \tag{4.4}$$

$$\left.\begin{array}{l}\text{If } |D\ PEDLS| \geqslant EL\ CY1| \\ D\ PEDLS = |EL\ CY1| * SIGN\ D\ PEDLS\end{array}\right\} \tag{4.5}$$

4.2 Auxiliary servo and mechanical linkages

$$D\ AX\ YI = CCY6 * D\ PEDLS \tag{4.6}$$

$$D\ XB\ Y = (CCY2 * D\ AX\ YI) - (CCY3 * D\ AY\ FB) \tag{4.7}$$

$$D\ VLV\ Y = -(CCY4 * D\ XB\ Y) - (CCY5 * D\ AUTO\ Y) \tag{4.8}$$

$$D\ AY\ DT = \text{Function}\ (D\ VLV\ Y) \tag{4.9}$$

$$D\ AUX\ Y = \int (D\ AY\ DT)\,dt \tag{4.10}$$

If |D AUX Y| < |EL CY2|
D AUX Y = D AUX Y (4.11)

If |D AUX Y| ≥ |EL CY2|
D AUX Y = |EL CY2| * SIGN D AUX Y (4.12)

If |D XB Y| < |EL CY3|
D DEAD Y = O (4.13)

If |D XB Y| ≥ |EL CY3|
D DEAD Y = (|D XB Y| − |EL CY3|) * SIGN D XB Y (4.14)

D AY FB = D AUX Y + D YFB1 − D YFB2 (4.15)

If S YFB1 is off
D YFB1 = 0 (4.16)

If S YFB1 is on
D YFB1 = CCY11 (4.17)

If S YFB2 is off
D YFB2 = 0 (4.18)

If S YFB2 is on
D YFB2 = CCY11 (4.19)

If D PEDLS ≤ EL CY3
and THETA T ≤ EL CY5
and D AA DT < 0
then S YFB1 is on
otherwise S YFB1 is off (4.20)

If D PEDLS ≥ EL CY6
and THETA T ≥ EL CY4
and D AA DT > 0
then S YFB2 is on
otherwise S YFB2 is off (4.21)

If THETA T ≥ EL CY4
and EL CY3 < D PEDLS < EL CY6
and D PED DT > 0
or
if THETA T ≤ EL CY5
and EL CY3 < D PEDLS < EL CY6
and D PED DT < 0
then S D PED is on
otherwise S D PED is unchanged (4.22)

If S YFB1 is on
and D AUX Y + (D AUX A * CCY8) ≥ CCY10
S YFB1 is switched off (4.23)

If S YFB1 is on
and D AUX Y + (D AUX A * CCY8) < CCY10
S YFB1 remains on (4.24)

If S YFB2 is on
and D AUX Y + (D AUX A * CCY8) ≤ CCY9
S YFB2 is switched off (4.25)

If S YFB2 is on
and D AUX Y + (D AUX A * CCY8) > CCY9
S YFB2 remains on (4.26)

4.3 Mechanical linkages and rotor head

THE TU = (TH CT MD) + (CCY7 * (D AUX Y + CCY8 * D AUX A)) (4.27)

If |THE TU| < |EL CY4|
THETA T = THE TU } (4.28)

If |THE TU| ≥ |EL CY4|
THETA T = |EL CY4| * SIGN THE TU } (4.29)

APPENDIX II: AN ALTERNATIVE COLLECTIVE STICK MODEL

As stated in Section 3.3, a simplification of the behaviour of the collective stick has been used in the flying controls model. A more comprehensive collective stick model, which determines the torque required to move the stick, is presented here. This was derived by Packer and used in the Wessex mathematical model (Refs 3–6). A diagram for the model is shown in Figure A1 and some comments about its operation are given below:

(i) THEC ST is the angle of the collective stick relative to the helicopter x - axis.

(ii) DL TH CS is the angle of the stick relative to the middle of its range of travel.

(iii) THC SET is the initial condition for THEC ST after an integrator reset arising through SC ST7; it represents the stick angle at a mechanical stop.

(iv) When SC ST8 is on, the stick has reached a mechanical stop.

(v) If SC ST6 is on, the pilot is moving the stick towards its nearer stop, or pushing it against this.

(vi) D XSTK is the displacement of the cross-bar joining the pilot's and co-pilot's collective sticks.

(vii) T SPRING is the torque acting at the c. of g. of the collective stick, caused by the balance spring.

(viii) T ACCN is that component of torque acting on the collective stick c. of g. due to gravity and the motion of the airframe at the point where the stick is pivoted.

(ix) If SC ST4 is on, the stick is moving towards or is being pushed against, the closer mechanical stop, by the external torque (T EX). Note that the stick cannot move away from the stop unless T EX exceeds the frictional torque (T FRIC) and is of opposite sign.

(x) SC ST7 indicates when the stick is at a mechanical stop and is being driven into it.

(xi) The total torque acting on the stick c. of g. (T TOT) is obtained by subtracting the frictional torque (T FRIC), which opposes motion, from T EX.

(xii) The angular acceleration of the stick relative to the helicopter (TH CS DD) is obtained by dividing T TOT by the moment of inertia of the stick about its pivot (1/CCA12).

(xiii) The angular velocity of the stick relative to the helicopter (TH CS DP) is obtained by integrating TH CS DD.

(xiv) Switch SC ST1 is engaged when the stick has come to rest.

(xv) Switch SC ST2 is engaged when the absolute value of the external torque (T EX) is less than (or equal to) the absolute value of the frictional torque (T FRIC).

(xvi) SC ST3 is on when both SC ST1 and SC ST2 are on; i.e. when the stick is at rest and there is insufficient torque to move it.

(xvii) S PIL A is a switch which enables the pilot to more the stick freely.

(xviii) When S PIL A is on and the stick is not at either stop, both SC ST5 and SC ST9 are on and the stick's angular velocity (TH CS DP) is determined by the pilot (TCS D PL) through THD SET.

(xix) S FRIC is the friction lock on the collective stick. When this is on the stick may not be moved.

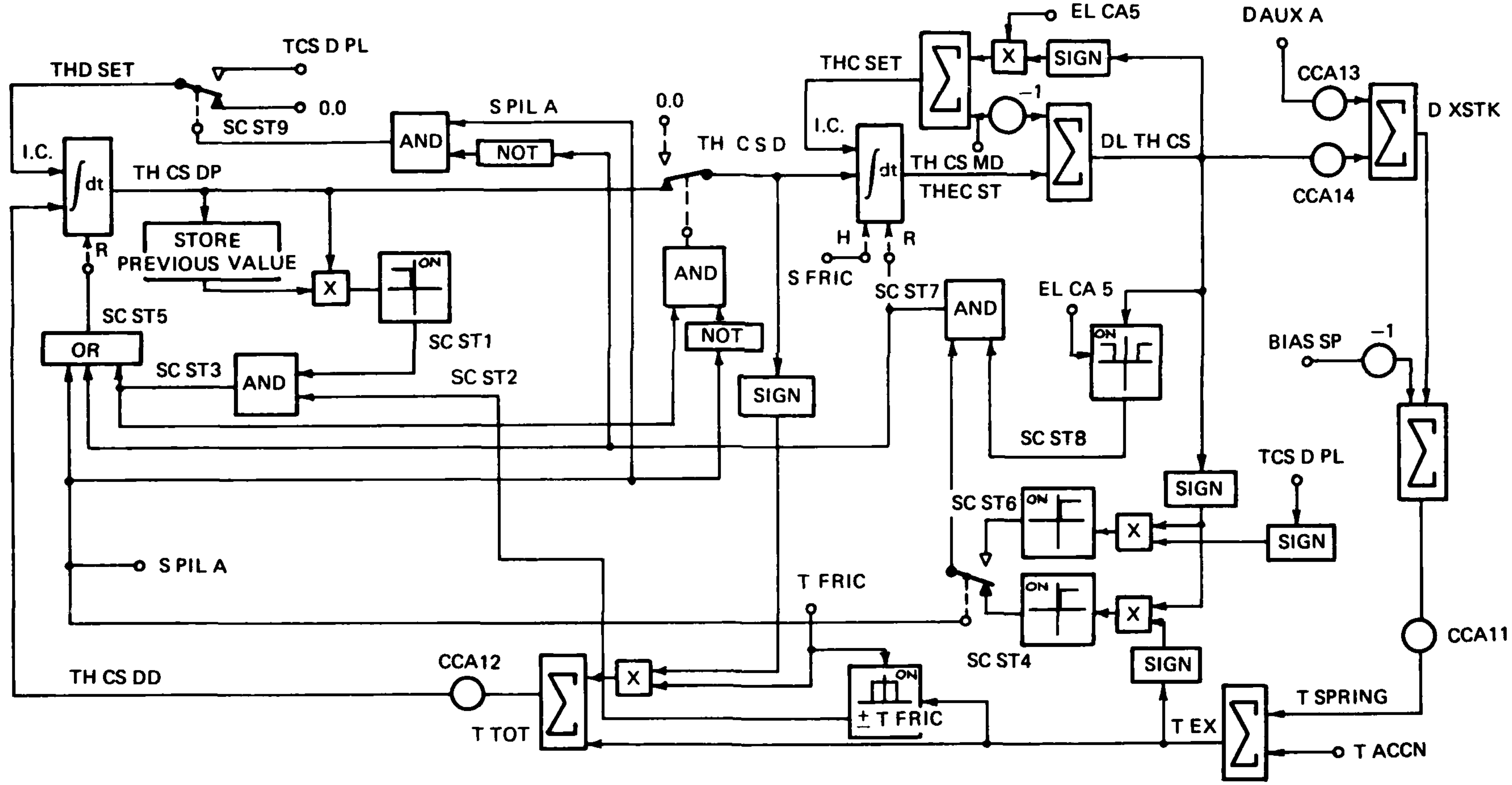

FIG A1. WESSEX COLLECTIVE STICK MODEL

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