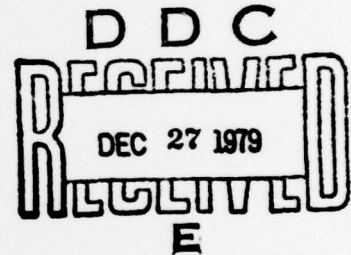




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AERODYNAMICS NOTE 387



**SEA KING MK. 50 HELICOPTER**  
**FLIGHT CONTROL SYSTEM**

**A MATHEMATICAL MODEL OF THE AFCS**  
**(AUTOSTABILIZER/AUTOPILOT MODE)**

by

C. R. GUY

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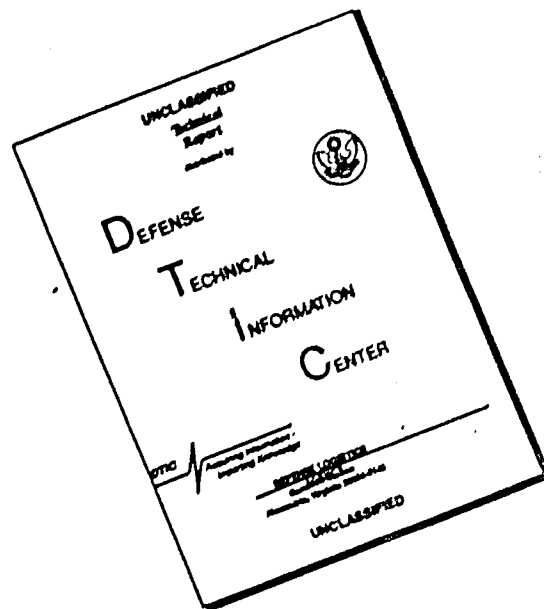


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9 AERODYNAMICS NOTE 387

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A MATHEMATICAL MODEL OF THE AFCS  
(AUTOSTABILIZER/AUTOPILOT MODE).

11 Feb. 79  
by

12 28

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14 ARL/AERO NOTE-387

SUMMARY

A mathematical model for the autostabilizer/autopilot mode of the automatic flight control system (AFCS) for the Sea King Mk.50 helicopter is presented. An outline of the autostabilizer/autopilot used in the aircraft is given first, followed by a description of the mathematical model, which includes a representation of each major element of the aircraft system.

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## 1. INTRODUCTION

The operation of the automatic flight control system (AFCS) for the Sea King Mk.50 helicopter is conveniently subdivided into two modes, the autostabilizer/autopilot mode and the ASW mode. The object of this report is to describe a mathematical model of the system in the autostabilizer/autopilot mode. This is used in conjunction with models representing the flying controls (Ref. 1) and the ASW mode of the AFCS (Ref. 2). Together, the flying controls and the AFCS form the control systems for the helicopter. In turn, the control systems model combines with mathematical models of the aerodynamics/kinematics and sonar cable/transducer to form a complete helicopter/sonar dynamics model which 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 autostabilizer/autopilot model presented here has some similarities to the autopilot representation used in the Wessex helicopter mathematical model developed by Packer at Weapons Research Establishment† (Refs 3–6). In addition, a simplified model of the Sea King autostabilizer/autopilot has been described in Reference 7.

The model presented here makes representations of the elements forming the autostabilizer/autopilot used in the aircraft (unlike the model outlined in Reference 7, which represents only overall control laws). A full description of the AFCS used in the aircraft is given in References 8–11.

Section 2 of this document describes the operation and components used in the autostabilizer/autopilot of the aircraft. Section 3 outlines the mathematical model; this is subdivided into pitch channel, roll channel, yaw stabilizer/heading hold and barometric altitude hold. Block diagrams for the model are presented (Figs 2–5) and its equations are given in Appendix I. The block diagrams are constructed from diagrams of the physical system contained in References 8 and 9 and from circuit diagrams and data for the AFCS supplied by Louis Newmark Ltd, manufacturers of the equipment. They form a link between the physical system and the mathematical model. The equations representing the characteristics of each element can be deduced from the block diagrams.

## 2. THE AUTOSTABILIZER/AUTOPILOT MODE OF THE AIRCRAFT AFCS

The autostabilizer/autopilot mode of the AFCS provides the following facilities:

- (i) Stabilization in roll, pitch and yaw.
- (ii) Heading hold
- (iii) Barometric altitude hold.

References 8 and 9 describe the aircraft AFCS autostabilizer/autopilot mode and this section summarizes these documents.

The facilities of the AFCS are transmitted to the flying controls through the electrohydraulic servo valves (Moog valves) of the auxiliary servo unit. This unit contains four jacks together with their associated valves and linkages. A diagram of a typical jack is shown in Figure 6. It can be deduced that the flapper position of the servo valve controls the pressure on the pilot valve which in turn controls the jack piston. These servo valves, one per channel, receive electrical demand signals from the AFCS and act in series with the pilot's own control demands, but with only limited authority. Extended authority of control is provided by automatic inching (beeping) of the cyclic-pitch trim facility (pitch and roll channels) and by 'open-loop' operation (yaw and collective channels) in the auxiliary servo unit.

† Now Defence Research Centre, Salisbury.

## **2.1 Autostabilizer mode**

When the autostabilizer facility is engaged, the system functions as an attitude-holding stabilizer. The aircraft is stabilized at the pitch and roll attitudes and at the heading established by the pilot through the flying controls. Damping is applied to motion in each of these channels.

### **2.1.1 Pitch and roll channels**

Functioning of the system in pitch and roll is similar and is best explained with reference to Figure 7. In each channel the attitude signal from the vertical gyro unit is suitably modified in the amplifier unit and mixed with signals from the stick canceller and pilot's controller. The output from the amplifier unit is a demand signal which the auxiliary and primary servos convert to cyclic changes of blade pitch angle at the rotor head. The resulting controlled change in tilt of the rotor disc is a correction which opposes the initial disturbance of aircraft attitude.

Pitch trim and roll trim controls are provided on the pilot's controller. When release of cargo or consumption of fuel results in a shift of the aircraft centre of gravity (c. of g.), for example, trimming becomes necessary to keep the servo valves of the auxiliary servo unit operating around mid-travel.

### **2.1.2 Yaw channel**

The yaw channel provides both heading hold and yaw rate damping depending whether or not the pilot is applying pedal-force. When he applies pedal-force, the channel functions as a damper only and when he removes foot pressure, heading hold automatically takes effect. A yaw force link in the tail rotor control run is the sensor which detects pedal-force.

During a pilot controlled turn, aircraft yaw rate is sensed by the rate gyro unit and this signal is modified in the amplifier unit to provide a damping signal which acts in opposition to the pilot's demand (Fig. 8). Meanwhile, heading is internally 'followed-up' in the amplifier unit, so that the system automatically locks on to the new heading immediately the manoeuvre is complete.

## **2.2 Autopilot mode**

Autopilot facilities are heading hold and barometric altitude hold. Functioning of the pitch and roll channels is not affected when these facilities are engaged and disengaged.

### **2.2.1 Heading hold**

This operates to hold the aircraft on the course being pursued at the moment of engagement. When the pilot ceases to apply foot pressure to the pedals, the yaw force link allows heading hold to become effective. From Figure 9 it can be seen that aircraft heading information is transmitted via the pilot's controller. The heading signal is provided by a compass system and a heading trim knob on the pilot's controller allows the pilot to make changes in heading without using the pedals. The pilot's controller signal is combined with the damping signal from the rate gyro in the amplifier unit and this signal is passed through the channel selector unit to the electro-hydraulic valve of the yaw auxiliary servo which actuates the tail rotor blades via the linkages of the flying controls. Heading hold is maintained by controlling tail rotor blade pitch angle. During manoeuvres requiring large power changes, 'open-loop' operation of the auxiliary servo causes some movement of the pedals in response to AFCS demand (Ref. 8).

### **2.2.2 Barometric altitude hold**

Barometric altitude hold enables the aircraft to be stabilized at any preselected altitude up to 3000 m. Engagement is made when the aircraft is at the desired (datum) height and the facility enables this height to be maintained. Altitude is sensed by the barometric altimeter part of the altitude control unit and the output signal from this device is supplied via the amplifier unit and channel selector unit to the electro hydraulic valve of the collective auxiliary servo (Fig. 10). The auxiliary servo operates the primary jacks through the flying control linkages to provide height control by means of variation in collective pitch of the main rotor blades.

'Open-loop' operation of the system provides automatic trimming of the collective stick if large AFCS collective channel demand signals arise (Ref. 8).

Changes in height may be made by the pilot after depressing the barometric altitude manoeuvre button on the collective lever. When this button is preseed, barometric altitude hold is removed; when released, barometric altitude hold is re-established relative to the new value of barometric altitude to which the aircraft has been flown.

### 3. THE AFCS AUTOSTABILIZER AUTOPILOT MODE MATHEMATICAL MODEL

#### 3.1 Pitch channel (Fig. 2 and Appendix I, equations (1.1) to (1.10))

##### 3.1.1 Composition

The pitch channel autostabilizer is represented in the model by the following components:

- (i) The pitch channel of the vertical gyro unit, which is modelled as the aircraft's pitch attitude angle,  $THE\ HE^\dagger$ , multiplied by gain  $CAP1$ . The vertical gyro output signal is  $E\ GYRO\ P$ .
- (ii) The stick canceller, which provides a control position signal and is represented by the pitch stick angle,  $THE\ STK$ , multiplied by gain  $CAP2$ .
- (iii) The pitch trim signal from the pilot's controller,  $THE\ TRM$ .
- (iv) The amplifier unit, which itself comprises:
  - a) A gearing and filter circuit, which operates on the vertical gyro signal, to produce proportional and derivative components ( $E\ GD\ P$ ) of this signal.  $E\ GD\ P$  is obtained from  $E\ GYRO\ P$  by an approximate differentiator network.
  - b) A summing junction which combines the control position and pitch trim signals to form signal  $E\ CTRL\ P$ .
  - c) A summing junction and gain factor which represent the servo-amplifier. Inputs to this are  $E\ GD\ P$ ,  $E\ GYRO\ P$  and  $E\ CTRL\ P$ , all multiplied by their appropriate gains, together with  $E\ HOV\ P$ , which is the pitch channel signal arising from the ASW mode of AFCS operation (see Ref. 2).
  - d) Switch  $S\ STAB$ , which is the autostabilizer on/off switch.
- (v) The channel selector unit switch,  $S\ PITCH$ . It should be noted that the channel selector unit in the aircraft includes hardover switches, but as these are used only for test purposes, they have not been included in the model.
- (vi) The servo valve of the auxiliary servo jack, which provides a linear output ( $D\ AUTO\ P$ ) until the limits ( $\pm EL\ AP1$ ) are reached.  $D\ AUTO\ P$  represents the flapper valve displacement from its central position (see Fig. 6) and  $\pm EL\ AP1$  represent the maximum and minimum travel of the flapper. The limits control the AFCS authority over fore-and-aft cyclic blade pitch angle ( $\pm 10\%$  of total blade angular travel). The modelling of the remaining parts of the auxiliary servo unit are detailed in Reference 1.

##### 3.1.2 Operation

Engagement of  $D\ AUTO\ P$  is made through switches  $S\ STAB$  and  $S\ PITCH$ . The attitude holding and stabilizing characteristics of the system are achieved by use of the geared pitch attitude angle signal and its approximate derivative in the control law (see Appendix I). The stick canceller signal partially cancels the attitude signal so as to allow a wider range of attitude control without exceeding the authority limit  $EL\ AP$  and also improves the response of the aircraft to pilot demands (Ref. 12). ASW mode and pitch trim signals are included through the terms  $E\ HOV\ P$  and  $THE\ TRM$  respectively, the latter being used to bias the control position signal when *c. of g. changes occur*, to avoid saturation of the servo valve.

#### 3.2 Roll channel (Fig. 3 and Appendix I, equations (2.1) to (2.13))

The form and functioning of the roll channel autostabilizer is similar to that of the pitch channel except for a lag network, which operates on the combined control position and trim

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

signal (E CTRL R). An input limiting circuit (limits are  $\pm EL AR2$ ) prevents saturation of the servo valve which would otherwise occur with prolonged lateral displacements of the cyclic control column (PHI STK). In addition, the signs associated with the attitude term and its derivative are different from those of the pitch channel. This arises from the sign convention adopted for each variable in the entire aircraft/control systems/cable model.

### 3.3 Yaw stabilizer and heading hold (Fig. 4 and Appendix I, equations (3.1) to (3.23))

#### 3.3.1 Composition

The yaw stabilizer and heading hold is represented in the model by the following components:

- (i) The direction gyro of the gyro magnetic compass, which comprises the aircraft yaw angle, PSI HE, multiplied by gain CAY1.
- (ii) The pilot's controller, where the heading trim signal, PSI TRM, is added to the direction gyro signal to form the output signal PSI HET.
- (iii) The rate gyro unit, which comprises the aircraft yaw rate (R HEH) multiplied by gain CAY6. The output signal is E YAW G.
- (iv) The amplifier unit, which is broken down into the following parts:
  - a) The synchro circuit, which provides the heading error signal, E ERR Y, by subtracting the reference heading signal (PSI REF) from the trimmed aircraft heading signal (PSI HET). The synchro has two alternative states, 'follow' and 'hold', according to the sense of switches S STAB (the autostabilizer mode selector switch) and S PEDLS (the yaw force link switch which is on when pedal-force is applied and vice-versa). When S STAB is disengaged and also when both S STAB and S PEDLS are engaged together, the synchro functions as a servo loop, following-up the trimmed heading signal. Follow-up action results from any change in aircraft heading (PSI HE) or alteration of PSI TRM. In this condition, the heading error signal (E ERR Y) is continuously being maintained near zero by means of the (synchro) integrator/feedback loop. When S STAB is engaged but S PEDLS is disengaged, the follow-up action is interrupted by breaking the feedback path; i.e. the (synchro) integrator input signal PSI R DT becomes zero and the output (the reference heading PSI REF) remains constant. This is the heading hold condition of the synchro and enables (reference) heading changes to be made through pedal movement.
  - b) The amplifier unit integrator circuit, which provides an integral of heading error signal (E INT Y) when S PEDLS is off. The output of the amplifier unit integrator circuit is clamped to a maximum value ( $\pm EL AY2$ ), avoiding possible undesirable effects when the auxiliary servo goes into open-loop operation. Also, the rate of change of E INT Y is restricted to  $\pm EL AY3$ . When S PEDLS is engaged, the amplifier unit integrator circuit is held at its null condition (the negative feedback loop ensures that output E INT Y equals the input, which is zero).
  - c) The summing junction, which adds the geared heading error signal (E ERR Y multiplied by CAY3) to the geared heading integrated error signal (E INT Y multiplied by CAY4). The summing junction, integrator circuit and synchro constitute what is referred to in Reference 9 as the yaw synchronizer circuit.
  - d) The servo-amplifier, in which the geared yaw damping signal from the rate gyro is combined with the error plus integrated error signal, E PI Y, to form the output signal E OUT Y1. E PI Y is the yaw synchronizer summer signal after switching by S PEDLS. The autostabilizer on/off switch S STAB is connected to the servo-amplifier output.
- (v) The channel selector unit and servo valve, which are similar to those described in Section 3.1.

#### 3.3.2 Operation

Engagement of D AUTO Y is made through switches S STAB and S YAW. When these are on and the yaw force link switch (S PEDLS) is off, heading hold and yaw rate damping

are provided. When S STAB, S YAW and S PEDLS are all on, the channel functions as a yaw damper only.

Yaw damping is provided by means of the rate gyro signal in the control equations (Appendix I) and the heading hold control equations use the combined heading error signal, E ERR Y together with the integral of heading error signal E INT Y, the latter being included to improve the long-term accuracy of heading hold.

### **3.4 Barometric altitude hold (Fig. 5 and Appendix I, equations (4.1) to (4.18))**

#### **3.4.1 Composition**

The barometric altitude hold is represented in the model by the following components:

- (i) The altitude control unit, which produces an output signal (V H ERR) proportional to barometric altitude error. V H ERR is proportional to the difference between the prevailing altitude (Z HEE) and the altitude (H BAR A) existing at the time when the barometric height hold switch S BA, was engaged. A sample and hold device is used to produce this characteristic. Note that the sign conventions for Z HEE and H BAR A are opposite.
- (ii) The collective clutched pick-off, which operates in a similar fashion to the altitude control unit model. If S CLU is on (i.e. if either the barometric altitude hold (S BA) or radio altitude hold (S RA) switches are engaged), EC ST1 is proportional to the difference between the prevailing collective stick angle (THEC ST) and the clutched collective stick angle (TH CLU) existing at the time when S CLU was engaged.
- (iii) The amplifier unit, which consists of:
  - a) A gearing and filter circuit which operates on the altitude control unit signal (V H ERR) via switch S BA to act as a gust filter, minimizing the effect of fluctuations of signal amplitude caused by local air turbulence.
  - b) A servo-amplifier which sums signals from the gearing and filter circuit (V ERR SM), the collective clutched pick-off (EC ST1) and the radio altitude hold facility of the AFCS. Two separate radio altitude signals exist, one for vertical velocity (E HOV A1) and the other for altitude error plus its integral (E HOV A2). The modelling of the radio altitude hold facility is described in Reference 2. The amplifier unit output signal (E OUT A3) is equal to the servo-amplifier output signal (E OUT A1) after switching through S BA and S RA.
- (iv) The channel selector unit and servo valve, which are similar to those described in Section 3.1.

#### **3.4.2 Operation**

Engagement of D AUTO A is made through the channel selector switch (S COLL) and the barometric height hold switch S BA. At the moment when S BA is engaged, the height datum (H BAR A) is set and subsequent deviations in height are fed through the collective channel to stabilize the aircraft at H BAR A. When a change in height is made, S BA must be switched off. Immediately S BA is re-engaged, altitude hold is re-established relative to the new value of barometric altitude to which the aircraft has been flown.

If open-loop spring operation takes place due to large error signals occurring, the clutched pick-off signal varies in opposition to the barometric height error signal. The feedback arrangement is such that the amount of collective lever movement is approximately in proportion to the amplitude of the barometric altitude error signal, thus improving the stability of the altitude hold when large barometric height error signals occur.

### **4. CONCLUDING REMARKS**

A detailed mathematical model of the AFCS autostabilizer/autopilot mode for the Sea King Mk.50 helicopter has been outlined. This is to be used in conjunction with similarly detailed models of the flying controls and AFCS ASW mode to form the complete control systems model. Representations of the elements used in the autostabilizer/autopilot of the aircraft have been made including limits and other 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

CAAI .....	5	} Constants
CAPI .....	6	
CARI .....	6	
CAYI .....	8	
D AUTO A		} Servo valve positions
D AUTO P		
D AUTO R		
D AUTO Y		
DL STCK		} Collective clutched pick-off signals
EC STI		
E CS HV		Combined collective clutched pick-off and ASW mode signal
E CT R		Output signal from roll channel lag network and limiter
E CTRL P		} Stick canceller and demodulator output signals in pitch and roll respectively
E CTRL R		
E ERR Y		Yaw synchro error signal
E GD P		} Gearing and filter circuit output signals in pitch and roll respectively
E GD R		
E GYRO P		} Vertical gyro and demodulator output signals in pitch and roll respectively
E GYRO R		
E HOV A1		} ASW mode output signals
E HOV A2		
E HOV P		
E HOV R		
E INT Y		} Yaw integrator circuit signals
E IY DL		
E IY DT		
EL AA1		} Limits
EL API		
EL ARI .....	2	
EL AYI .....	3	
E OUT A		} Servo-amplifier output and switching signals
E OUT A1 .....	3	
E OUT P		
E OUT PI .....	2	
E OUT R		
E OUT R1 .....	2	
E OUT Y		
E OUT Y1 .....	2	
E PI Y		Yaw servo-amplifier input signal
E R LG		Roll channel lag network output signal
E YAW G		Yaw rate gyro and demodulator output signal

H BAR A H ERROR	}	Barometric altimeter, C.P.T. and demodulator signals
PHI HE PSI HE THE HE	}	Attitude angle of helicopter relative to earth in roll, yaw and pitch respectively
PHI STK THE STK	}	Cyclic stick angles in roll and pitch respectively
PHI TRM PSI TRM THE TRM	}	Trim angle signals in roll, yaw and pitch respectively
PSI HET		Direction gyro and heading trim output signal
PSI R DT PSI REF PSI RP	}	Yaw synchro signals
R HEH		Yaw rate of helicopter relative to earth
s		Laplace operator
S BA, S RA		Barometric and radio altitude hold selector switches respectively
S CLU		Collective clutched pick-off switch
S COLL S PITCH S ROLL S YAW	}	Channel selector switches
S PEDLS		Yaw force link switch
S STAB		Autostabilizer/autopilot mode selector switch
TAAI TAPI TARI ..... 3	}	Time constants
THEC ST		Collective stick angle
TH CLU		Collective clutched pick-off signal
V ERR SM V ERR SI	}	Barometric altitude hold gearing and filter circuit signals
V H ERR		Barometric altimeter, C.P.T. and demodulator output signal
Z HEE		Altitude (positive downwards)

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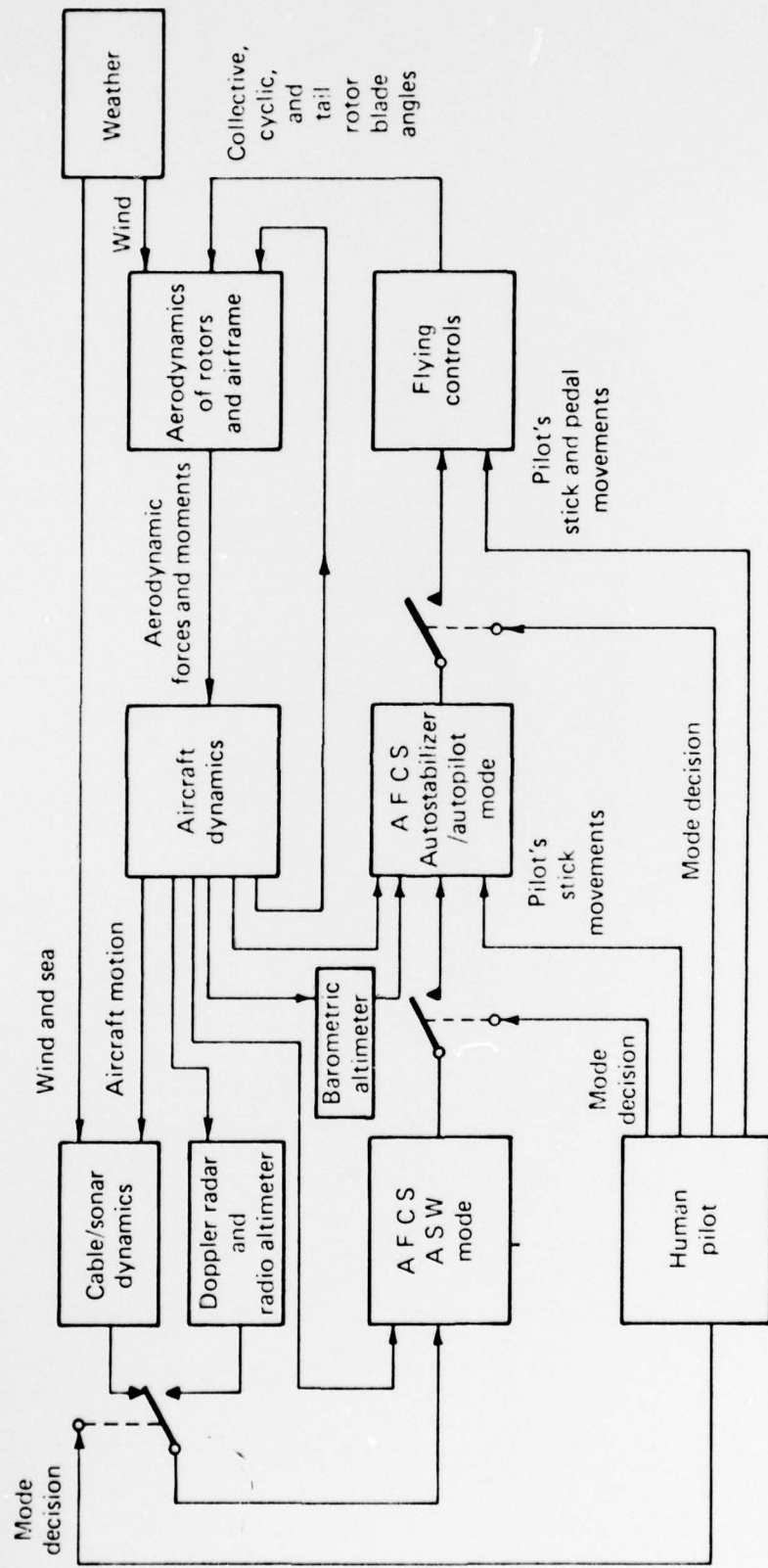


FIG 1. OVERALL BLOCK DIAGRAM FOR THE HELICOPTER/SONAR SYSTEM

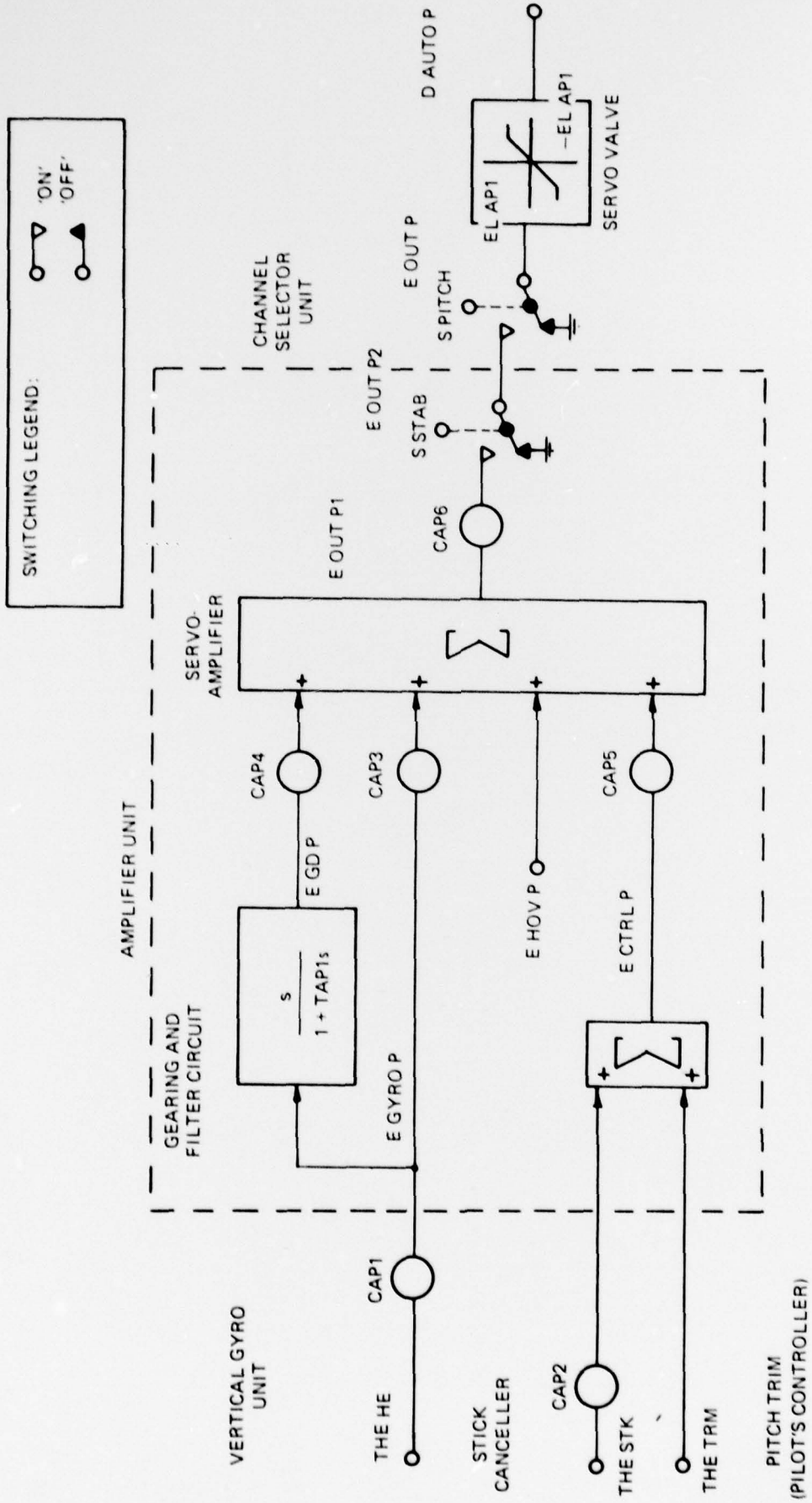


FIG 2. AFCS AUTOSTABILIZER/AUTOPILOT MODE (PITCH CHANNEL)

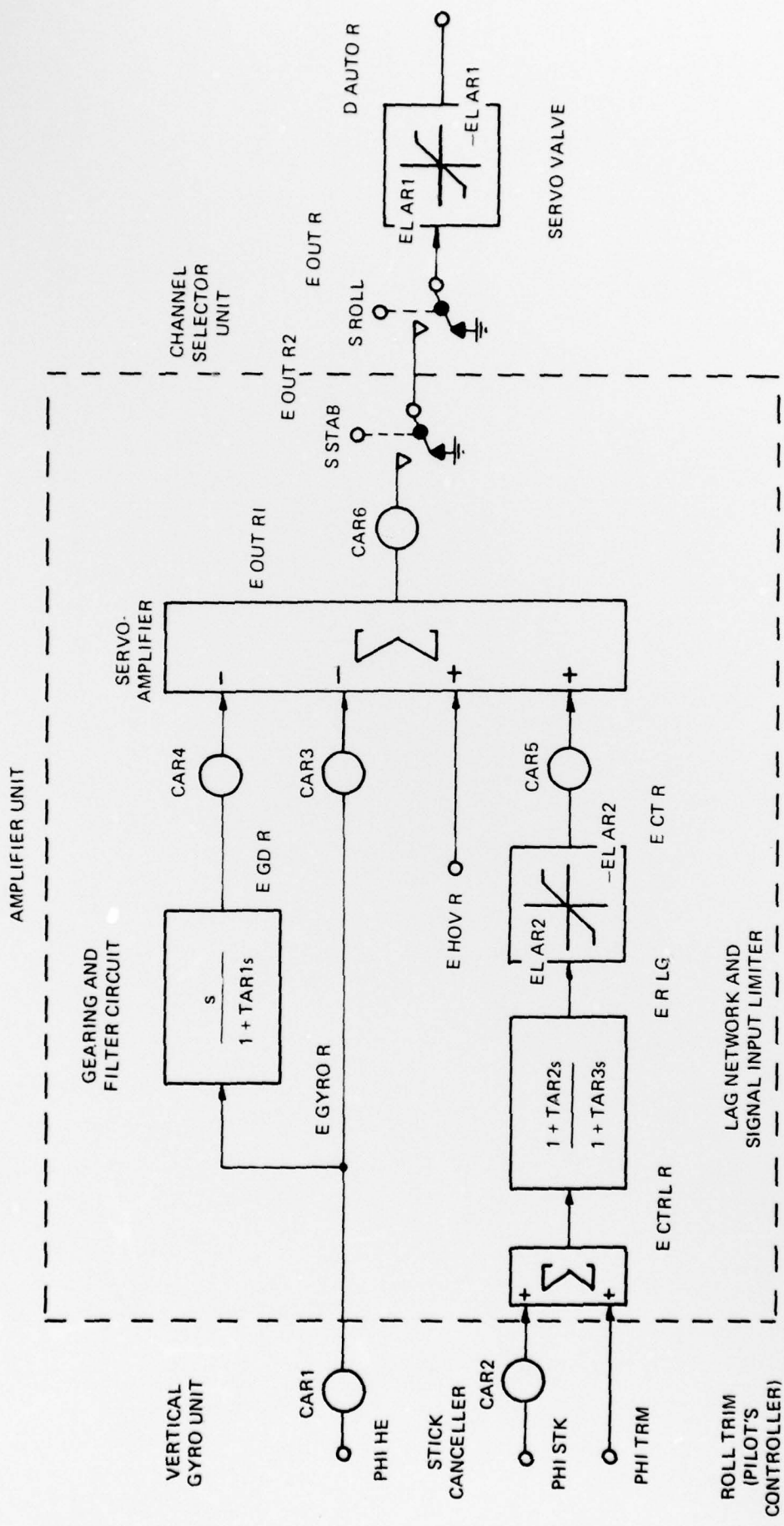


FIG 3. AFCS AUTOSTABILIZER/AUTOPILOT MODE (ROLL CHANNEL)

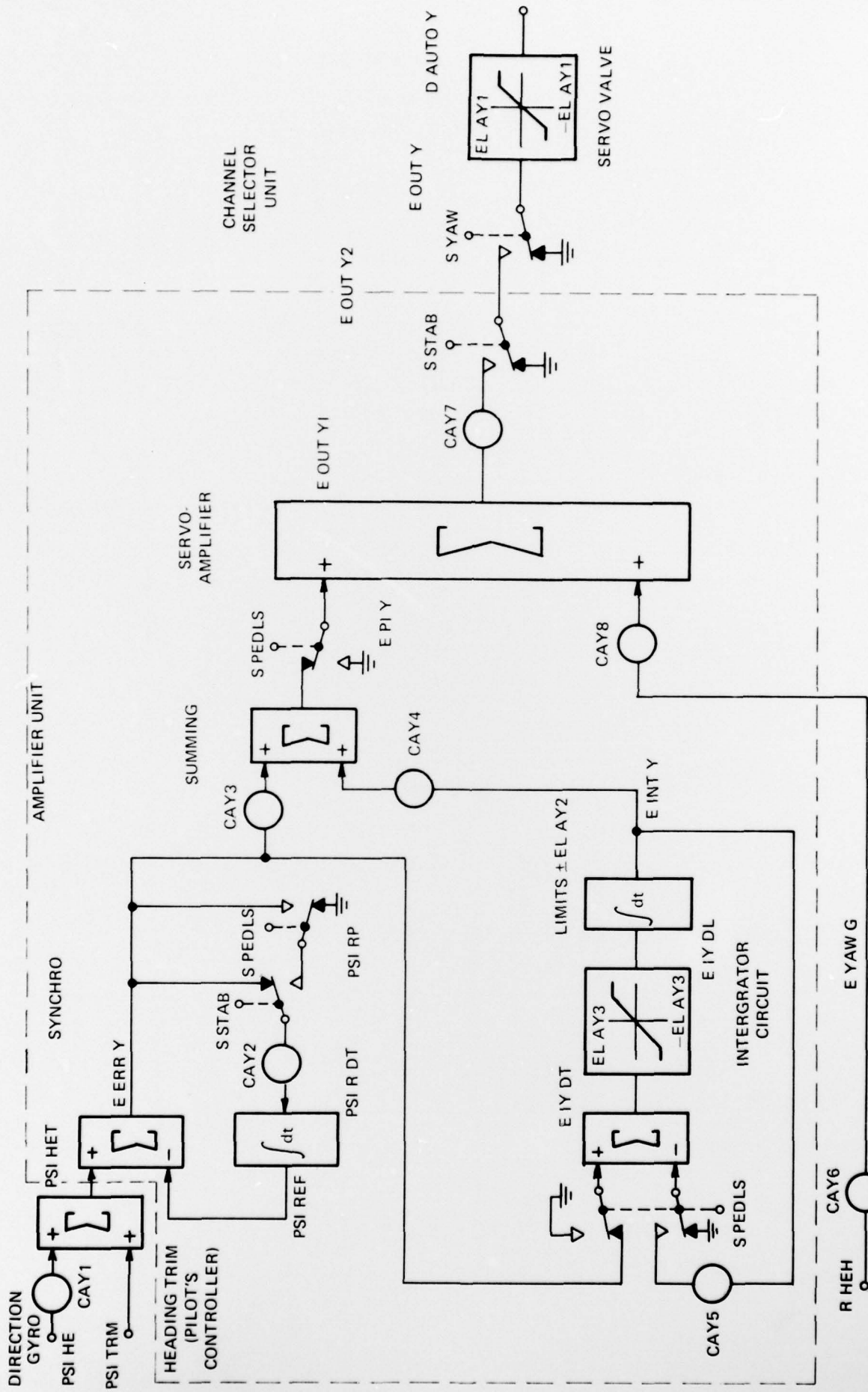


FIG 4. AFCS AUTOSTABILIZER/AUTOPILOT MODE (YAW STABILIZER AND HEADING HOLD)

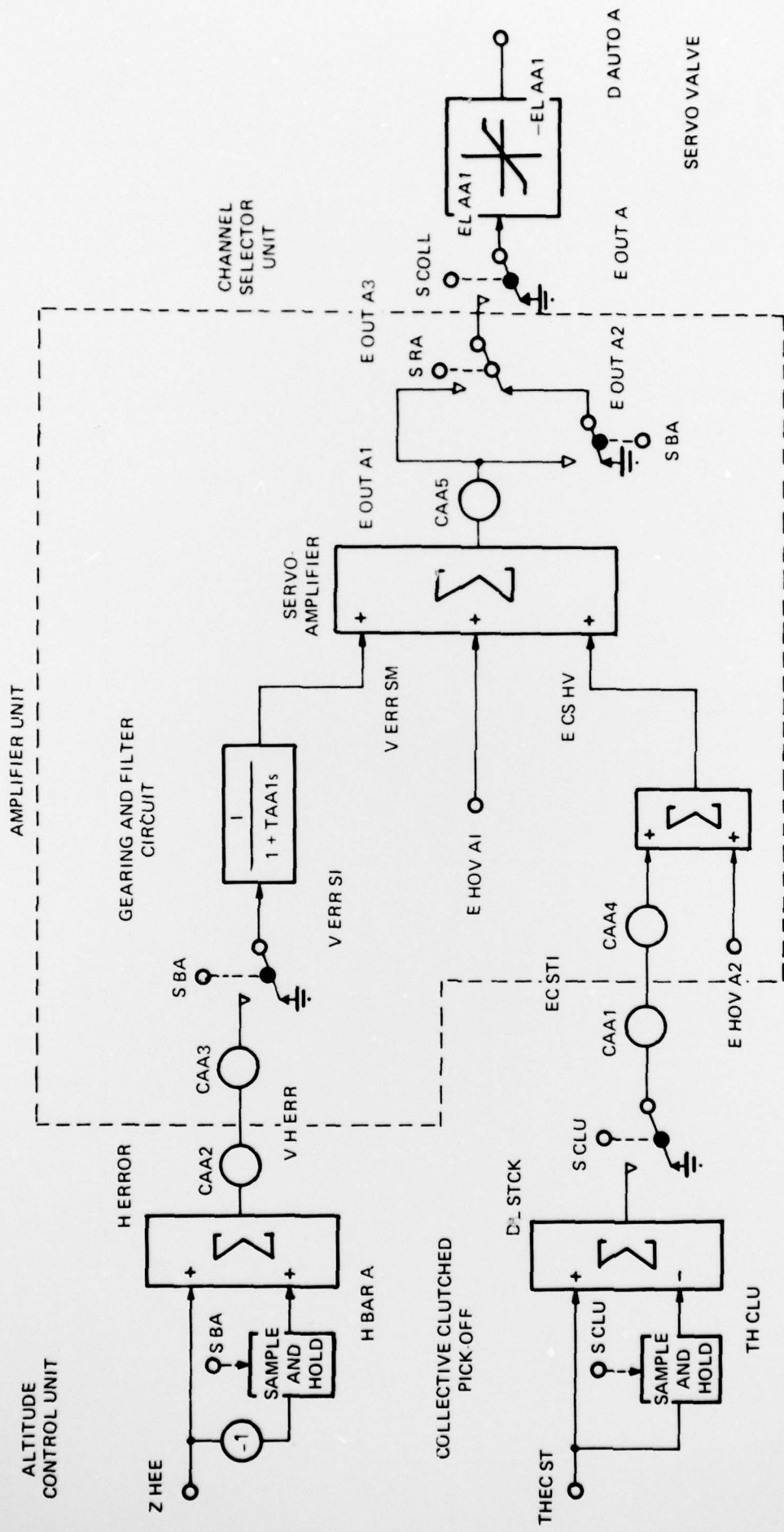


FIG 5. AFCS AUTOSTABILIZER/AUTOPILOT MODE (BAROMETRIC ALTITUDE HOLD)

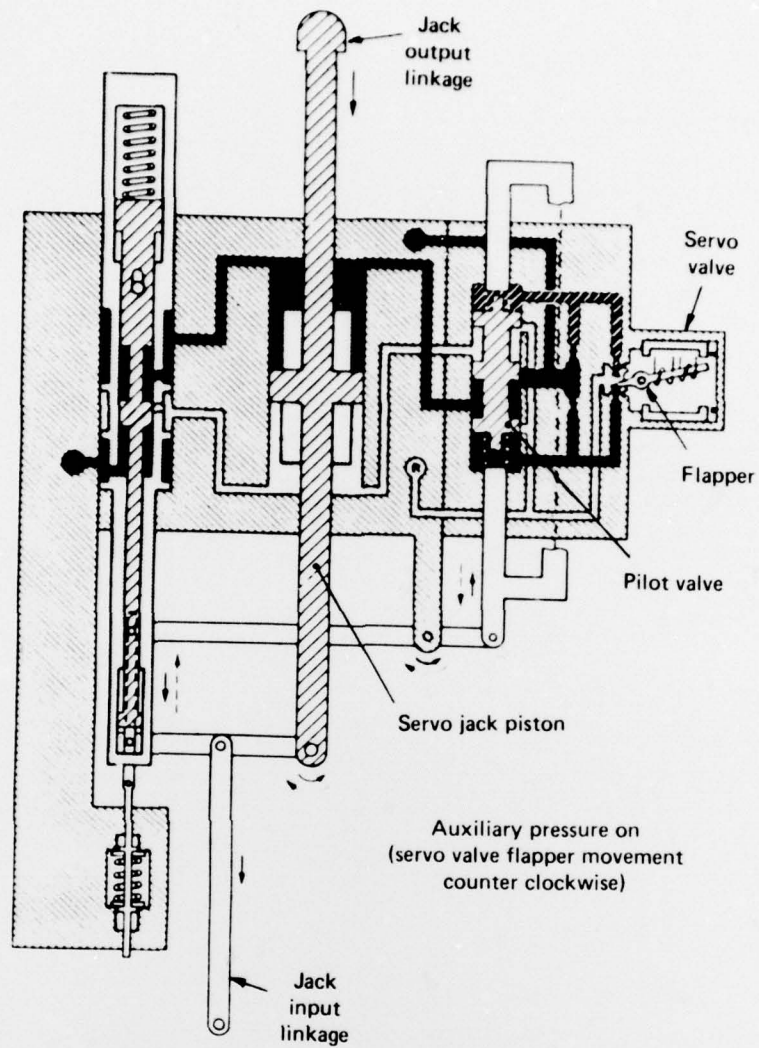


FIG 6. AUXILIARY SERVO UNIT JACK (TYPICAL)  
(TAKEN FROM REF 8)

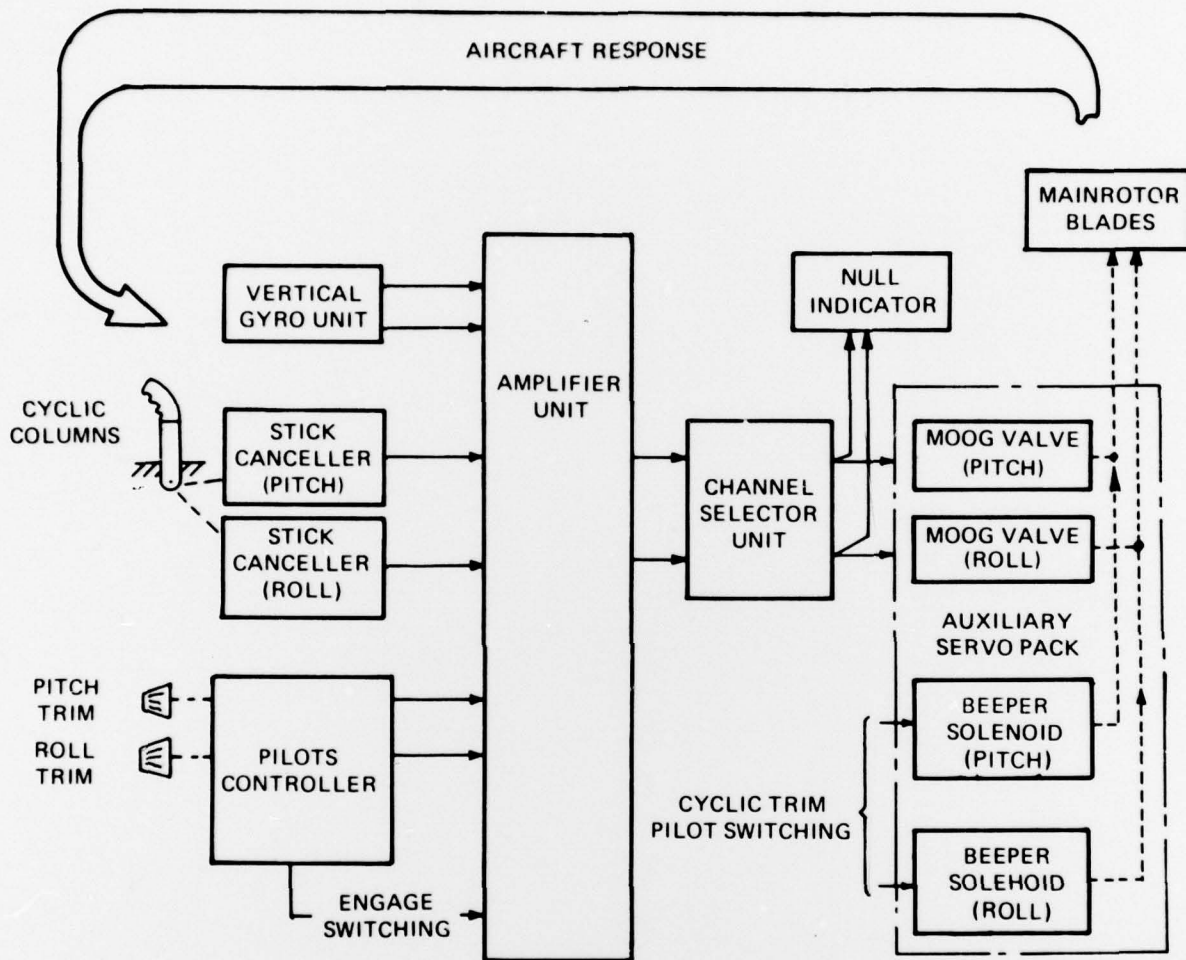


FIG 7. AUTOSTABILIZER/AUTOPILOT FACILITIES, PITCH AND ROLL CHANNELS  
(TAKEN FROM REF 8)

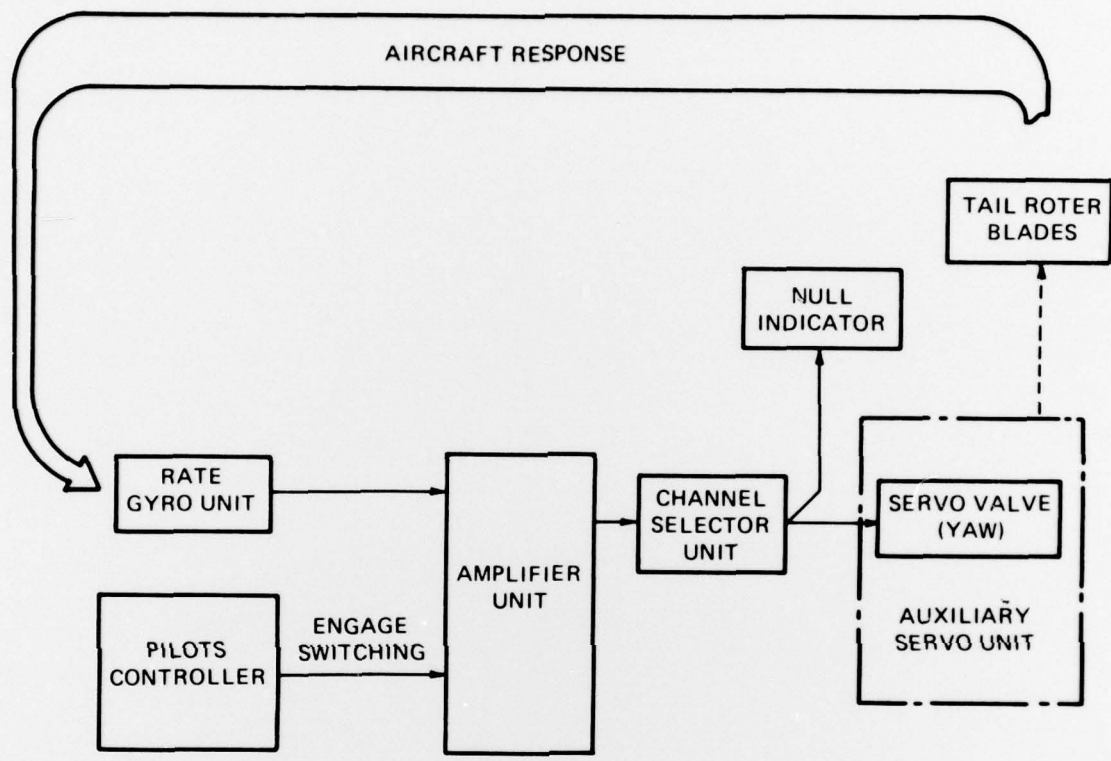


FIG 8. AUTOSTABILIZER FACILITY, YAW CHANNEL (TAKEN FROM REF 8)

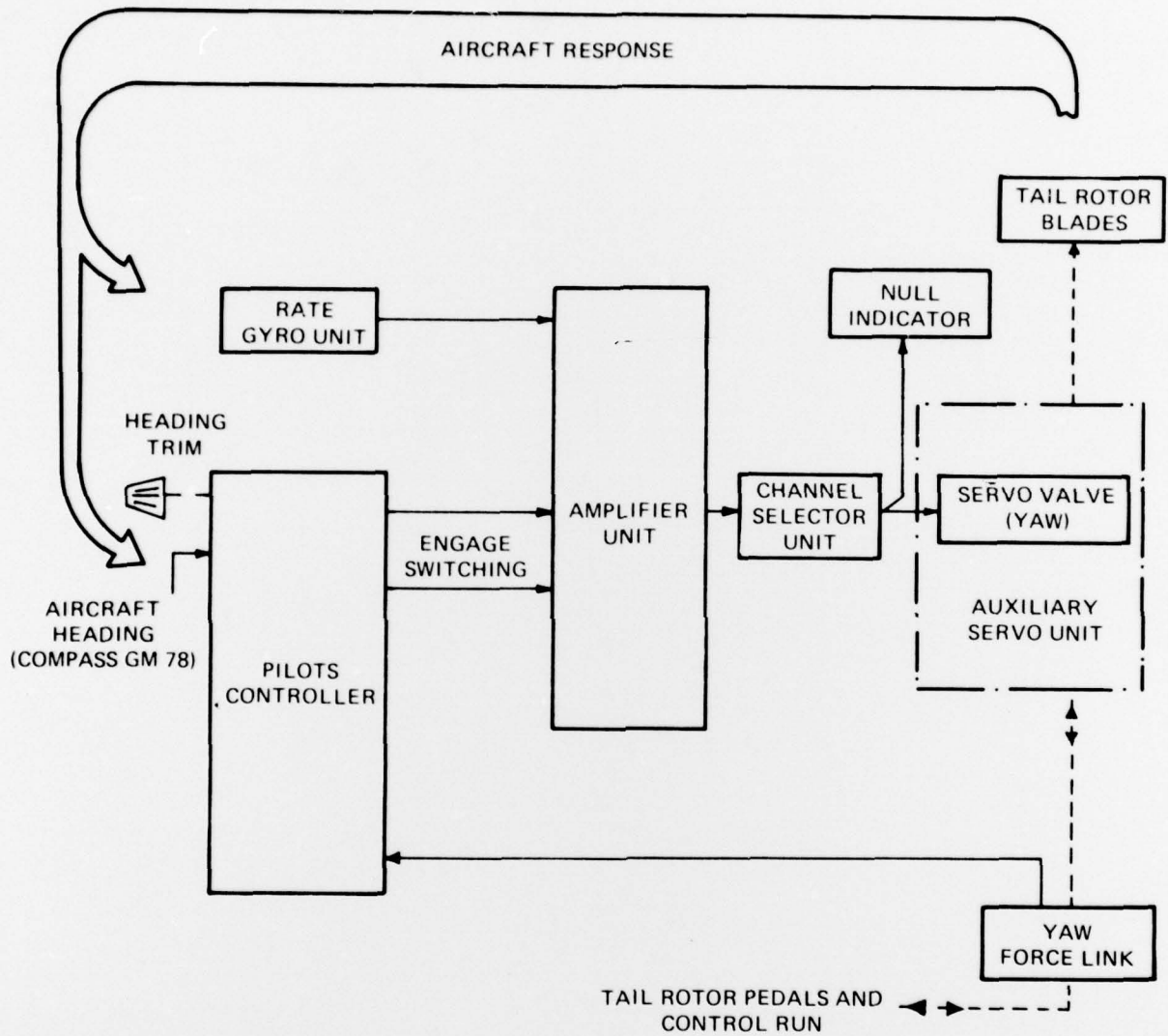


FIG 9. HEADING HOLD, YAW CHANNEL (TAKEN FROM REF 8)

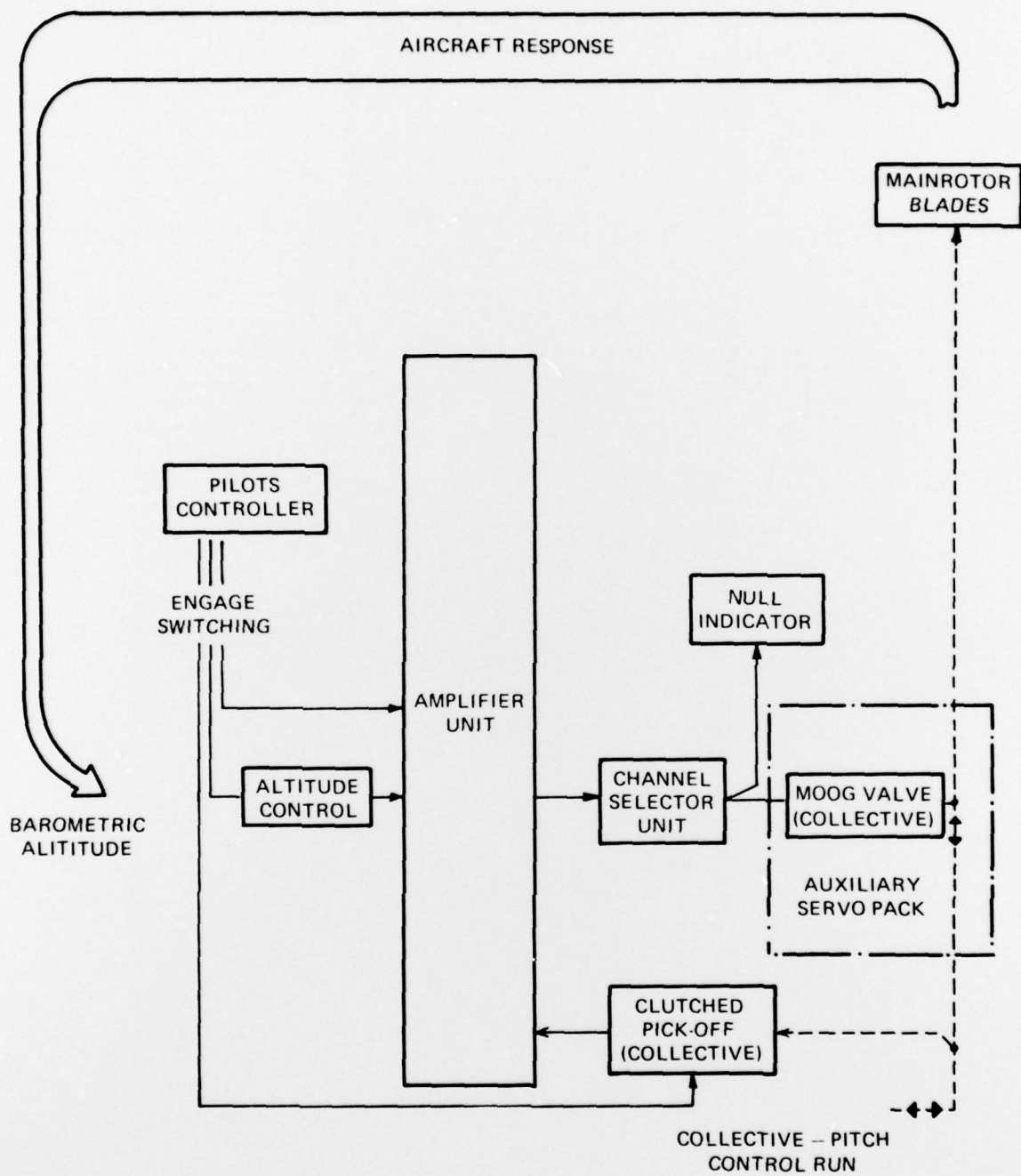


FIG 10. BAROMETRIC ALTITUDE HOLD, COLLECTIVE CHANNEL (TAKEN FROM REF 8)

**APPENDIX I: EQUATIONS FOR THE AFCS AUTOSTABILIZER/AUTOPILOT MODE  
MATHEMATICAL MODEL**

**1. PITCH CHANNEL (Fig. 2)**

**1.1 Vertical gyro unit**

$$E \text{ GYRO P} = \text{CAP1} * \text{THE HE} \quad (1.1)$$

**1.2 Amplifier unit**

**1.2.1 Gearing and filter unit**

$$E \text{ GD P} = \left( \frac{s}{1 + \text{TAP1}s} \right) * E \text{ GYRO P} \quad (1.2)$$

**1.2.2 Stick canceller and pitch trim (pilot's controller) input signals**

$$E \text{ CTRL P} = (\text{CAP2} * \text{THE STK}) + (\text{THE TRM}) \quad (1.3)$$

**1.2.3 Servo-amplifier and switching**

$$E \text{ OUT P1} = (\text{CAP4} * E \text{ GD P}) + (\text{CAP3} * E \text{ GYRO P}) \\ + (E \text{ HOV P}) + (\text{CAP5} * E \text{ CTRL P}) \quad \left. \vphantom{E \text{ OUT P1}} \right\} (1.4)$$

$$\left. \begin{array}{l} \text{If S STAB is off} \\ E \text{ OUT P2} = 0 \end{array} \right\} (1.5)$$

$$\left. \begin{array}{l} \text{If S STAB is on} \\ E \text{ OUT P2} = \text{CAP6} * E \text{ OUT P1} \end{array} \right\} (1.6)$$

**1.3 Channel selector unit**

$$\left. \begin{array}{l} \text{If S PITCH is off} \\ E \text{ OUT P} = 0 \end{array} \right\} (1.7)$$

$$\left. \begin{array}{l} \text{If S PITCH is on} \\ E \text{ OUT P} = E \text{ OUT P2} \end{array} \right\} (1.8)$$

**1.4 Servo valve**

$$\left. \begin{array}{l} \text{If } E \text{ OUT P} < |EL \text{ API}| \\ D \text{ AUTO P} = E \text{ OUT P} \end{array} \right\} (1.9)$$

$$\left. \begin{array}{l} \text{If } E \text{ OUT P} \geq |EL \text{ API}| \\ D \text{ AUTO P} = |EL \text{ API}| * \text{SIGN}(E \text{ OUT P}) \end{array} \right\} (1.10)$$

**2. ROLL CHANNEL (Fig. 3)**

**2.1 Vertical gyro unit**

$$E \text{ GYRO R} = \text{CAR1} * \text{PHI HE} \quad (2.1)$$

**2.2 Amplifier unit**

**2.2.1 Gearing and filter circuit**

$$E \text{ GD R} = \left( \frac{s}{1 + \text{TAR1}s} \right) * E \text{ GYRO R} \quad (2.2)$$

### 2.2.2 Stick canceller and roll trim (pilot's controller) input signals

$$E \text{ CTRL R} = (\text{CAR2} * \text{PHI STK}) + (\text{PHI TRM}) \quad (2.3)$$

### 2.2.3 Lag network and signal input limiter

$$E \text{ R LG} = \left( \frac{1 + \text{TAR2}s}{1 + \text{TAR3}s} \right) * E \text{ CTRL R} \quad (2.4)$$

$$\left. \begin{array}{l} \text{If } |E \text{ R LG}| < |E \text{ L AR2}| \\ E \text{ CT R} = E \text{ R LG} \end{array} \right\} (2.5)$$

$$\left. \begin{array}{l} \text{If } |E \text{ R LG}| \geq |E \text{ L AR2}| \\ E \text{ CT R} = |E \text{ L AR2}| * \text{SIGN}(E \text{ R LG}) \end{array} \right\} (2.6)$$

### 2.2.4 Servo-amplifier and switching

$$\left. \begin{array}{l} E \text{ OUT R1} = (\text{CAR5} * E \text{ CT R}) + (E \text{ HOV R}) \\ \quad - (\text{CAR3} * E \text{ GYRO R}) - (\text{CAR4} * E \text{ GD R}) \end{array} \right\} (2.7)$$

$$\left. \begin{array}{l} \text{If S STAB is off} \\ E \text{ OUT R2} = 0 \end{array} \right\} (2.8)$$

$$\left. \begin{array}{l} \text{If S STAB is on} \\ E \text{ OUT R2} = \text{CAR6} * E \text{ OUT R1} \end{array} \right\} (2.9)$$

### 2.3 Channel selector unit

$$\left. \begin{array}{l} \text{If S ROLL is off} \\ E \text{ OUT R} = 0 \end{array} \right\} (2.10)$$

$$\left. \begin{array}{l} \text{If S ROLL is on} \\ E \text{ OUT R} = E \text{ OUT R2} \end{array} \right\} (2.11)$$

### 2.4 Servo valve

$$\left. \begin{array}{l} \text{If } |E \text{ OUT R}| < |E \text{ L AR1}| \\ D \text{ AUTO R} = E \text{ OUT R} \end{array} \right\} (2.12)$$

$$\left. \begin{array}{l} \text{If } |E \text{ OUT R}| \geq |E \text{ L AR1}| \\ D \text{ AUTO R} = |E \text{ L AR1}| * \text{SIGN}(E \text{ OUT R}) \end{array} \right\} (2.13)$$

## 3. YAW STABILIZER AND HEADING HOLD (Fig. 4)

### 3.1 Direction gyro and heading trim (pilot's controller)

$$\text{PSI HET} = (\text{CAY1} * \text{PSI HE}) + (\text{PSI TRM}) \quad (3.1)$$

### 3.2 Rate gyro unit

$$E \text{ YAW G} = \text{CAY6} * R \text{ HEH} \quad (3.2)$$

### 3.3 Amplifier unit

#### 3.3.1 Synchro

$$E \text{ ERR Y} = \text{PSI HET} - \text{PSI REF} \quad (3.3)$$

$$\left. \begin{array}{l} \text{If S PEDLS is off} \\ \text{PSI RP} = 0 \end{array} \right\} (3.4)$$

$$\left. \begin{array}{l} \text{If S PEDLS is on} \\ \text{PSI RP} = E \text{ ERR Y} \end{array} \right\} (3.5)$$

$$\left. \begin{array}{l} \text{If S STAB is off} \\ \text{PSI R DT} = \text{CAY2} * E \text{ ERR Y} \end{array} \right\} (3.6)$$

$$\left. \begin{array}{l} \text{If S STAB is on} \\ \text{PSI R DT} = \text{CAY2} \cdot \text{PSI RP} \end{array} \right\} (3.7)$$

$$\text{PSI REF} = \int (\text{PSI R DT}) dt \quad (3.8)$$

### 3.3.2 Integrator circuit

$$\left. \begin{array}{l} \text{If S PEDLS is off} \\ \text{E IY DT} = \text{E ERR Y} \end{array} \right\} (3.9)$$

$$\left. \begin{array}{l} \text{If S PEDLS is on} \\ \text{E IY DT} = -(\text{CAY5} \cdot \text{E INT Y}) \end{array} \right\} (3.10)$$

$$\left. \begin{array}{l} \text{If } |\text{E IY DT}| < |\text{EL AY3}| \\ \text{E IY DL} = \text{E IY DT} \end{array} \right\} (3.11)$$

$$\left. \begin{array}{l} \text{If } |\text{E IY DT}| \geq |\text{EL AY3}| \\ \text{E IY DL} = |\text{EL AY3}| \cdot \text{SIGN}(\text{E IY DT}) \end{array} \right\} (3.12)$$

$$\text{E INT Y} = \int (\text{E IY DL}) dt \quad (3.13)$$

$$\left. \begin{array}{l} \text{If } |\text{E INT Y}| < |\text{EL AY2}| \\ \text{E INT Y} = \text{E INT Y} \end{array} \right\} (3.14)$$

$$\left. \begin{array}{l} \text{If } |\text{E INT Y}| \geq |\text{EL AY2}| \\ \text{E INT Y} = |\text{EL AY2}| \cdot \text{SIGN}(\text{E INT Y}) \end{array} \right\} (3.15)$$

### 3.3.3 Servo amplifier, summing and switching

$$\left. \begin{array}{l} \text{If S PEDLS is off} \\ \text{E PI Y} = (\text{CAY3} \cdot \text{E ERR Y}) + (\text{CAY4} \cdot \text{E INT Y}) \end{array} \right\} (3.16)$$

$$\left. \begin{array}{l} \text{If S PEDLS is on} \\ \text{E PI Y} = 0 \end{array} \right\} (3.17)$$

$$\text{E OUT Y1} = (\text{E PI Y}) + (\text{CAY8} \cdot \text{E YAW G}) \quad (3.18)$$

$$\left. \begin{array}{l} \text{If S STAB is off} \\ \text{E OUT Y2} = 0 \end{array} \right\} (3.19)$$

$$\left. \begin{array}{l} \text{If S STAB is on} \\ \text{E OUT Y2} = \text{CAY7} \cdot \text{E OUT Y1} \end{array} \right\} (3.20)$$

### 3.4 Channel selector unit

$$\left. \begin{array}{l} \text{If S YAW is off} \\ \text{E OUT Y} = 0 \end{array} \right\} (3.21)$$

$$\left. \begin{array}{l} \text{If S YAW is on} \\ \text{E OUT Y} = \text{E OUT Y2} \end{array} \right\} (3.22)$$

### 3.5 Servo valve

$$\left. \begin{array}{l} \text{If } |\text{E OUT Y}| < |\text{EL AY1}| \\ \text{D AUTO Y} = \text{E OUT Y} \end{array} \right\} (3.23)$$

$$\left. \begin{array}{l} \text{If } |\text{E OUT Y}| \geq |\text{EL AY1}| \\ \text{D AUTO Y} = |\text{EL AY1}| \cdot \text{SIGN}(\text{E OUT Y}) \end{array} \right\} (3.24)$$

## 4. BAROMETRIC ALTITUDE HOLD (Fig. 5)

### 4.1 Altitude control unit

$$\left. \begin{array}{l} \text{H ERROR} = \text{Z HEE} + \text{H BAR A} \\ \text{where} \\ \text{H BAR A} = -\text{Z HEE at time when S BA is engaged} \end{array} \right\} (4.1)$$

$$V H ERR = CAA2 \cdot H ERROR \quad (4.2)$$

#### 4.2 Collective clutched pick-off

$$DL STCK = THEC ST - TH CLU$$

where

$$TH CLU = THEC ST \text{ at time when } S CLU \text{ is engaged} \quad (4.3)$$

$$\begin{aligned} \text{If } S CLU \text{ is off} \\ EC ST1 = 0 \end{aligned} \quad (4.4)$$

$$\begin{aligned} \text{If } S CLU \text{ is on} \\ EC ST1 = CAA1 \cdot DL STCK \end{aligned} \quad (4.5)$$

#### 4.3 Amplifier unit

##### 4.3.1 Gearing and filter circuit

$$\begin{aligned} \text{If } S BA \text{ is off} \\ V ERR S1 = 0 \end{aligned} \quad (4.6)$$

$$\begin{aligned} \text{If } S BA \text{ is on} \\ V ERR S1 = CAA3 \cdot V H ERR \end{aligned} \quad (4.7)$$

$$V ERR SM = \left( \frac{1}{1 + TAA1s} \right) \cdot V ERR S1 \quad (4.8)$$

##### 4.3.2 Servo-amplifier and switching

$$E CS HV = (CAA4 \cdot EC ST1) + E HOV A2 \quad (4.9)$$

$$E OUT A1 = V ERR SM + E HOV A1 + E CS HV \quad (4.10)$$

$$\begin{aligned} \text{If } S BA \text{ is off} \\ E OUT A2 = 0 \end{aligned} \quad (4.11)$$

$$\begin{aligned} \text{If } S BA \text{ is on} \\ E OUT A2 = CAA5 \cdot E OUT A1 \end{aligned} \quad (4.12)$$

$$\begin{aligned} \text{If } S RA \text{ is off} \\ E OUT A3 = E OUT A2 \end{aligned} \quad (4.13)$$

$$\begin{aligned} \text{If } S RA \text{ is on} \\ E OUT A3 = CAA5 \cdot E OUT A1 \end{aligned} \quad (4.14)$$

#### 4.4 Channel selector unit

$$\begin{aligned} \text{If } S COLL \text{ is off} \\ E OUT A = 0 \end{aligned} \quad (4.15)$$

$$\begin{aligned} \text{If } S COLL \text{ is on} \\ E OUT A = E OUT A3 \end{aligned} \quad (4.16)$$

#### 4.5 Servo valve

$$\begin{aligned} \text{If } |E OUT A| < |EL AA1| \\ D AUTO A = E OUT A \end{aligned} \quad (4.17)$$

$$\begin{aligned} \text{If } |E OUT A| \geq |EL AA1| \\ D AUTO A = |EL AA1| \cdot SIGN(E OUT A) \end{aligned} \quad (4.18)$$

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16. *ABSTRACT*

*A mathematical model for the autostabilizer/autopilot mode of the automatic flight control system (AFCS) for the Sea King Mk.50 helicopter is presented. An outline of the autostabilizer/autopilot used in the aircraft is given first, followed by a description of the mathematical model, which includes a representation of each major element of the aircraft system.*

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