FLIGHT CONTROL SYSTEMS
PROPERTIES AND PROBLEMS
Volume II - Block Diagram Compendium

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The purpose of this program was to document and pass on experience to current and future generations of flight control engineers, hopefully, to prevent costly rediscovery of past mistakes and to stimulate trade studies between possible competing mechanizational approaches.

The documentation is divided into two volumes. Volume I (NASA CR-2500) contains the technical discussion while this volume is a compendium of stability augmentation system and autopilot block diagrams and descriptive material for 48 different types of aircraft. These provide a broad representation of the many mechanizational approaches which have been employed in the past.
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SECTION I

INTRODUCTION

This volume contains a compendium of SAS and autopilot block diagrams for some 48 attack, bomber, cargo, drone, fighter, research, and transport type aircraft. It also contains references to specific documents from which information was gleaned for this study.

This compendium incorporates and expands upon an earlier effort (Ref. 67) initiated by the A-18 Aerospace Control and Guidance Systems Committee of the Society of Automotive Engineers. It is by no means a complete exposition of systems past and present. There are many systems for which no information was available, and there are others for which the information available was incomplete or conflicting, and therefore not included here.

An initial attempt was made to put all block diagrams into a consistent format which identified functional blocks and associated transfer characteristics, functional switching, etc. However, it rapidly became apparent that such a task was beyond the scope of this program. Therefore in most instances the diagrams presented here have been reproduced directly from the original documents listed in the references. In all probability they reflect but one version of systems which may have undergone several modifications. Consequently, additions or revisions are solicited from those who make use of these volumes.
### SECTION II

#### BLOCK DIAGRAMS

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LATERAL CONTROL SYSTEM

BLOCK DIAGRAMS

A3J-1 LATERAL CONTROL SYSTEM
A3J-1 AUTOMATIC FLIGHT CONTROL SYSTEM
A3J-1 AUTOMATIC FLIGHT CONTROL SYSTEM
TO FLAP CONTROL SYSTEM

BLOCK DIAGRAM

HYDRAULIC SCHEMATIC

A3J-1 DIRECTIONAL CONTROL SYSTEM
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A-4 Yaw Channel
A-7A Pitch Axis
A-7A Roll Axis
A-7A Yaw Axis
B-52 Modified Yaw SAS Block Diagram

B-52 Modified Pitch SAS Block Diagram
B-52 Original Yaw Damper
B-52 Original AFCS
B-52 Longitudinal Control Wheel Steering
B-52 Lateral Control Wheel Steering
B-58 Stability Augmentation
B-58 Attitude Stabilization Mode

Pitch
B-58 Attitude Stabilization Mode

Lateral
B-58 Control Stick Steering Mode

C.S.S. SWITCH

Control Stick Steering Switch Depressed

STABILITY AUGMENTATION MODE

Control Stick Steering Switch Released

ATTITUDE STABILIZATION AND OPTIONAL MODES

SWITCHING SUBSYSTEM
B-58 Mach Mode
B-58 Mach-Altitude Mode
B-58 Constant Heading
B-58 Heading Nav Mode
B-58 Localizer Mode
B-58 Automatic Glide Path Mode
B-66 Autopilot
XB-70 Pitch Axis Augmentation
XB-70 Roll Axis Augmentation
XB-70 Yaw Axis Augmentation

**Legend**
- $X_T$: Yaw Trim Actuator Position
- $F_P$: Pilot Input Force
- $X_P$: Rudder Position (positive for right pedal forward)
- $K_{e,x}$: Altitude Gain $= \frac{\text{deg}}{\text{in}}$
- $K_{p,r}$: Body Axis Yaw Rate Gain $= \frac{\text{deg}}{\text{sec}}$
- $K_{e,x}$: Altitude Error (above or below 0)
- $\delta_x$: Differential Servo in Degrees Equivalent Rudder
- $\delta_{x,k}$: Equivalent Input in Degrees Equivalent Rudder
- $\delta_r$: Rudder Deflection
- $K_g$: Gear Ratio (1 in gear up, 1 in gear down)
C-5A Pitch Stability Augmentation System

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<thead>
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<th>PITCH AUTOPILOT STATE</th>
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C-5A Roll Stability Augmentation System (SAS)
C-5A Yaw Stability Augmentation System (SAS)
C-5A Pitch Autopilot: Inner Loops
C-5A Pitch Autopilot: Radar Approach, Glide Slope and Flare Modes
C-5A Pitch Autopilot: Vernav, Terrain Following and Mach/IAS Modes
C-5A Pitch Autopilot: Altitude Capture and Altitude Hold Modes
C-5A Roll Autopilot: Inner Loops Including Control Wheel Steering
C-5A Roll Autopilot: VOR and TACAN Modes
CTD I

NAUTICAL MILES

\[ \psi_e \text{ DEG} \]

\[ \frac{1}{1 + 5s} \]

\[ N \]

\[ 0.044 \]

\[ 0.22 \]

\[ track \]

\[ 1 \]

\[ track \]

INTEGRAL

\[ q_c \]

\[ q_c \]

PROPORTIONAL

\[ \psi_e \text{ DEG} \]

\[ 1.65 \]

\[ 80. \]

\[ 100. \]

\[ \pm 45 \text{ DEG } \psi_e \]

COURSE CUT

\[ \theta \text{ DEG} \]

\[ C-SA \]

Roll Autopilot: Courseline and Air-Drop Modes

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<th>SUB-MODE ENTRY</th>
<th>CROSS-TRACK DEVIATION (CTD)</th>
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<td>CAPTURE</td>
<td>5.8 NM</td>
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C-5A Roll Autopilot: Courseline and Air-Drop Modes
C-5A Roll Autopilot: Localizer Mode, Including Autoland
C-5A Autothrottle Analytical Diagram
KC-135 Pitch Diagram

KC-135 Lateral-Directional Axis Diagram
XC-142A Pitch Control System Block Diagram
XC-142A Collective-Throttle System Block Diagram
K denotes a multiplier constant
\( q_c \) denotes airspeed scheduling
CSS denotes control stick steering
E-1B Roll Axis

S-2D/S-2E Roll Axis
Regulus II Lot I Autopilot
Q-2C Longitudinal Control System
Q-2C Roll Control System
BQM-34 Roll Axis
$K_0 = \text{pitch control gain} = G_0 \frac{G_{\Delta \theta}}{G_{\theta}} \text{ (deg/deg)}$

$K_h = \text{altitude control gain} = G_h \frac{G_{\Delta \theta}}{G_{\theta}} \text{ (deg/ft)}$

Note: $G_h$ is function of $h_0$ 

(i.e. $G_h = \frac{\Delta V}{\Delta P} \frac{dP}{dh} \bigg|_{h_0 = h_0}$)

MQM-74A Elevator Control System
$K_\phi = \text{ROLL CONTROL GAIN} = G_\phi \frac{G_{\delta a}}{G_x}$

MQM-74A Aileron Control System
F3H ROLL CHANNEL
F3H YAW CHANNEL
\[ \delta_e = K_\alpha (\alpha - \alpha_T) + K_\dot{\theta} \dot{\theta} \quad \text{when} \quad K_\alpha (\alpha - \alpha_T) + K_\dot{\theta} \dot{\theta} > 0 \]

\[ \delta_e = 0 \quad \text{when} \quad K_\alpha (\alpha - \alpha_T) + K_\dot{\theta} \dot{\theta} < 0 \]

F-86 Pitch-up Preventer
F-89 Sideslip Stability Augmenter
(FC) indicates block functions which are part of the flight controller - WG182B-1

Shaded blocks indicate automatic gain control functions of the airspeed compensator - PG7007B-3

(FA) indicates gain is varied as a function of differential pressure

(TAS) indicates gain is varied as a function of true air speed

Symbol indicates signal summing

F-89 Autopilot
---

**Pitch Damper**

- Short stroke, 0 to 20 feet
- Medium stroke, 20 to 90 feet
- Long stroke, above 90 feet

**Notes:**
- Open when rudder pedals are pressed.
- Phase I configuration
- Out block for phase I configuration
- Indicates gain scheduled as a function of airspeed and Mach number.

**Yaw Damper**

F-100 D/F Autopilot
POLAR I" COUPLER

ROLL RATE GYRO

YAW RATE GYRO

TURN CONTROL (FC)

DIRECTIONAL COUPLER

AUTOMIOT ENGAGE SWITCH

AILERON ENGAGED SWITCH

AILERON SERVO AMPLIFIERS

AILERON SERVOS

HYDRAULIC SYSTEM

VERTICAL GYRO

STABILATOR SERVO AMPLIFIER

STABILATOR SERVO

HYDRAULIC SYSTEM

PITCH INTEGRATOR

VERTICAL GYRO

PITCH RATE GYRO

PITCH CONTROL (FC)

AILERON INTEGRATOR

ROLL RATE GYRO

HYDRAULIC SYSTEM

Rudder Servo

--- DASHED LINE ENCLOSES DAMPER CONFIGURATION BLOCKS

F-101A Autopilot

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STABILATOR BRIDGE CIRCUIT

NOTES:

- Closed to B when Mach hold is engaged and closed to A when altitude hold is engaged.
- Closed to D when fire control mode is engaged.
- Open for attitude hold.
- Open for control stick steering and fire control.
- Closed for pitch attitude hold.
- Open for Mach hold.
- Closed for altitude hold.
- Closed for beam guidance.
- Closed for control stick steering.

TA scheduling, Mach scheduling, Airspeed scheduling, Altitude scheduling.
VERTICAL GYRO?
KOIES:
A A A A A A

OPEN WHEN AUTOPILOT IS ENGAGED.
OPEN FOR CONTROL STICK STEERING MODE.
SWITCH POSITION SHOWN FOR BEAM GUIDANCE MODE.
CLOSED AFTER AUTOPILOT IS ENGAGED.
CLOSED FOR FIRE CONTROL MODE.
OPEN FOR FIRE CONTROL MODE.
GAIN SCHEDULED AS A FUNCTION OF AIRSPEED.
INDICATES SUMMING POINT.

AILERON BRIDGE CIRCUIT

F-101B Autopilot

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NOTE:

⚠️ THIS LOOP IS NOT IN CIRCUIT WHEN DAMPER OR AUTOPILOT IS ENGAGED.

INDICATES GAIN SCHEDULED AS FUNCTION OF AIRSPEED.

INDICATES GAIN SCHEDULED AS FUNCTION OF MACH NUMBER.

RUDDER BRIDGE CIRCUIT

F-101B Autopilot

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PARALLEL SERVO

E-H Valve

Servo Ram

Engaged

Disengaged

Force Switch

System Engage

Power Actuator

F-101B Stick Pusher
F-102 YAW DAMPER

\[ \begin{align*}
  r & \rightarrow 1.25 \text{ deg/deg/sec} \\
  p & \rightarrow K_p \\
  f(q_c) & \rightarrow 0.171 \text{ deg/deg/sec} \\
  0.021 \text{ deg/deg/sec} & \rightarrow Ts + 1 \\
  f(q_c) & \rightarrow K_{6a} \\
\end{align*} \]

\[ \delta_r(\pm 6^\circ) \]

F-102 PITCH DAMPER

\[ \begin{align*}
  q & \rightarrow K_q \\
  Ts/Ts+1 & \rightarrow \text{Series servo} \\
\end{align*} \]
F-105A PITCH CHANNEL
F-105A ROLL CHANNEL
F-105A YAW CHANNEL
MANUAL MODE, YAW DAMPER AND TURN COORDINATOR MODE, AND AILAS MODE

SUMMING JUNCTIONS

\[ \times \] \text{REVERSIBLE}

\[ \times \] \text{REVERSIBLE}

COMPONENTS

OF AIR DATA COMPUTER

All switches shown in Damper mode.
F-111 Roll Channel Functional Diagram
F-111 Yaw Channel Functional Diagram
PILOT INPUT

COMMAND AUGMENTATION DYNAMICS

SENSORS

MODEL

STRUCTURAL FILTER

GAIN CHANGER

SERVO & LINKAGE DYNAMICS

PRE FILTER

ZERO CROSSING DETECTOR

INTEGRATOR

AERODYNAMICS

F-111 Adaptive Principle
T-38 Stability Augmentation System

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AVRO CF-100 Autopilot
There is no Pitch Axis in this autopilot.
Viggen Pitch Axis Stability Augmentation and Control Stick Steering Mode
Viggen Roll SAS-CSS Loop
Viggen Yaw Axis Stability Augmentation System
Viggen Pitch Outer Loops
Viggen Lateral Outer Loops
M2-F2 Lateral-Directional Flight Control System
X-15 Pitch Axis Configuration Block Diagram
X-15 Roll Axis Configuration
X-15 Yaw Axis Configuration
B-707 Autopilot
Rudder Channel

B-707 Autopilot
BASIC ROLL STABILIZATION

Position Servo

E/M Servo

Tach.

Synch.

ROLL PATH AND NAV MODES

Doppler 

Aux. Nav.

Heading Select

Select

Heading Synch.

Head Hold

D.G.

Limit

Turn Knob

Out of Det.

Detent

DC-8 Roll Axis
YAW STABILIZATION

\[ \phi_c \]

\[ \frac{K_{\text{yaw}} 48s}{(48s+1)(6.7s+1)(0.1s+1)} \]

Position Servo

Valve & Ram

Rudder Power Package

DC-8 Yaw Axis
L-188 Autopilot
CoPITCH RATE = GYRO AND A/P COUPLER

VERITCAL GYRO

LONGITUDINAL A/P GLIDE PATH MODE

ELEVATOR SERVO

OUTPUT LIMITER

DISPLACEMENT LIMITER

MAXIMUM INTEGRATOR

INTEGRATOR

MODULATOR AMPLIFIER

ALT ATTENUATOR

L-188 Autopilot
L-188 Autopilot
L-188 Autopilot

LI.

I LOHGI_u_DINA L

I

_PITCH RATE
GYRO & AJP-

COUPLER

VERTICAL
GYRO_J

mv/8-200 MV/Deg.
PROP ERECT to 20deg
Erection Rate,
1/20 Deg/SEC/deg.

Erection Rate=

ALT SENSOR

AIRSPEED ERROR
COMPENSATION

INTEGRATOR .07/5

Pitch Controller
Up Attitude

HYDRAULIC
AMPLIFIER &
MODULATING
PISTON

OUTPUT LIMITER

SERVO AMPLIFIER

POSITION
FEEDBACK

RATE
FEEDBACK

Xmp

LINKAGE

MAIN BOOST SPOOL

HYDRAULIC
RAM

EE/Xp

ELEVATOR SERVO

LONITUDINAL

AIRFRAME

AIRFRAME

SYNCHRONIZER

Switch Down when
A/P Engaged

FIXED EXC.

Pitch Controller

Switch Closed
Altitude
Control

Aerodyn
GESAC Roll Channel (F-4A)
GESAC Yaw Channel (F-4A)
Adaptable FCS Pitch Stability Augmentation System (F-4)
Adaptable FCS Lateral-Directional Stability Augmentation System (F-4)
Adaptable FCS Flight Condition Identifier (P-4)

\[ \delta_x = 12 \text{ ft} \]
\[ \frac{z_{\delta_e}}{z_{\alpha}} = 0.2 \]
Adaptable FCS Pitch Autopilot Functions (F-4)
Adaptable FCS Lateral/Directional Autopilot Functions
F-14 SFCS Pitch Axis
F-4 SPCS Directional Axis
Switching Logic \( SW = C_1 + C_2 + C_3 + SMRD \dot{\theta}_1 + SMRD \dot{\theta}_2 \)

\[
\begin{align*}
V_1 &= 1.66V \\
V_2 &= 2.42V \\
V_0 &= 4.56V \\
BIAS &= 30^\circ \alpha
\end{align*}
\]

Note: 0 to 100% Modulation Occurs for Range of 0 to \( V_0 \).

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<th>Nominal</th>
<th>Range</th>
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<td>0.5</td>
<td>0.25 - 1.0</td>
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<td>( K_2 )</td>
<td>15000</td>
<td>TBA</td>
</tr>
<tr>
<td>( K_3 )</td>
<td>6.0</td>
<td>3.0 - 12.0</td>
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<tr>
<td>( K_4 )</td>
<td>TBA</td>
<td></td>
</tr>
<tr>
<td>( K_5 )</td>
<td>TBA</td>
<td></td>
</tr>
<tr>
<td>( K_6 )</td>
<td>TBA</td>
<td></td>
</tr>
<tr>
<td>( K_7 )</td>
<td>0.843</td>
<td>TBA</td>
</tr>
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Comparator C\(_1\)

\[ \frac{K_7}{K_7+1} \]

Comparator C\(_2\)

\[ \frac{K_2}{(S+K_3)[S+50]} \]

Comparator C\(_3\)

\[ \frac{K_6}{(S+K_4)[S+K_5]} \]

Pulse Width Modulator

\( \dot{\theta}_1 \)

\[ \frac{K_7}{K_7+1} \]

\( \dot{\theta}_2 \)

\[ \frac{0.12}{V/\text{Deg/Sec}} \]

\( \alpha L_1 \)

\[ 0.6/V/\text{Deg} \]

\( \alpha R_1 \)

\[ 0.6/V/\text{Deg} \]

\( \alpha L_2 \)

\[ 0.6/V/\text{Deg} \]

\( \alpha R_2 \)

\[ 0.6/V/\text{Deg} \]

\( \beta_{C1} \)

\[ 0.166 \]

\( \beta_{C2} \)

\[ 0.166 \]

Logic and Switching

To CVU-1

To CVU-2

To CVU-3

To CVU-4

F-6 SFCS Stall Warning
F-4 Survivable Stabilator Actuator Package
F-4 SFCS Adaptive Gain Changer

\[ e = \frac{\text{ab}}{10} \rightarrow \text{KP} \]

\[ M_{\theta_s} \rightarrow \text{Actuator Model} \rightarrow \text{Self-Monitored} \]

\[ M_{\theta_s} \rightarrow \text{Interrogation Signal} \]

\[ M_{\theta_s} \rightarrow \text{A Reference} \]

\[ M_{\theta_s} \rightarrow \text{Stall Warning} \]

\[ \text{KP} \rightarrow \text{Hold Logic} \rightarrow \text{Dual Monitor} \rightarrow \text{Logic and Status} \]

\[ \text{KP} \rightarrow \text{Control Logic} \]

\[ \text{KP} \rightarrow \text{Voltage Controlled Oscillator} \]

\[ \text{KP} \rightarrow \text{Hold Logic} \rightarrow \text{Dual Threshold Monitor and Logic} \rightarrow \text{M}_{\theta_c} \rightarrow \text{CVU-1} \]

\[ \text{KP} \rightarrow \text{Hold Logic} \rightarrow \text{Dual Threshold Monitor and Logic} \rightarrow \text{M}_{\theta_c} \rightarrow \text{CVU-2} \]

\[ \text{KP} \rightarrow \text{Hold Logic} \rightarrow \text{Dual Threshold Monitor and Logic} \rightarrow \text{M}_{\theta_c} \rightarrow \text{CVU-3} \]

\[ \text{KP} \rightarrow \text{Hold Logic} \rightarrow \text{Dual Monitor} \rightarrow \text{M}_{\theta_c} \rightarrow \text{CVU-4} \]

\[ \text{KP} \rightarrow \text{Adaptive Gain Status} \]

\[ \text{KP} \rightarrow \text{CVU-4} \]

\[ \text{KP} \rightarrow \text{CVU-3} \]

\[ \text{KP} \rightarrow \text{CVU-2} \]

\[ \text{KP} \rightarrow \text{CVU-1} \]

\[ \text{KP} \rightarrow \text{CVU-4} \]

\[ \text{KP} \rightarrow \text{CVU-3} \]

\[ \text{KP} \rightarrow \text{CVU-2} \]

\[ \text{KP} \rightarrow \text{CVU-1} \]
(a) Pitch channel.

Grumman F9F-2 Attitude Command FBW
(b) Roll and yaw channels.

Grumman F9F-2 Attitude Command BFW
Stick controller

Servo amplifier

Servo motor

Elevator control system

Airplane

Follow-up canceler system

Amplifier and motor

Tachometer

Canceler selsyn

Pitch rate gyro

Pitch trim

$\delta_{cp}$

(a) Pitch channel.

Grumman F9F-2 Rate Command FBW
Grumman F9F-2 Normal-Acceleration Control System
SYSTEM BLOCK OF PITCH C.A.S.
ONE CHANNEL
FLT "39"

TWEAD I Pitch Axis
TREAD II Longitudinal Functional CAS Block Diagram
TWEAD II Lateral-Directional Functional CAS Block Diagram
F-4C TWEAD II Lateral Block Diagram
AVRO Pitch Rate Demand Control System (Duplex)
AVRO Roll Rate Demand Control System (Simplex with Comparison Monitor)
AVRO Rudder Control System Including Yaw Damper
(Simplex with Comparison Monitor)
LONGITUDINAL DIAGRAM

LYRANTAL DIAGRAM

F-100 Lear Rate Integrating Autopilot
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