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

Donald E. Johnston

Prepared by
SYSTEMS TECHNOLOGY, INC.
Hawthorne, Calif. 90250
for Flight Research Center

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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.
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A3J-1 LONGITUDINAL CONTROL SYSTEM
LATERAL CONTROL SYSTEM

Block Diagrams

A3J-1 LATERAL CONTROL SYSTEM
A3J-1 AUTOMATIC FLIGHT CONTROL SYSTEM
A3J-1 AUTOMATIC FLIGHT CONTROL SYSTEM
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A-4 Roll Channel
A-4 Yaw Channel
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A-7A Yaw Axis
B-52 Modified Yaw SAS Block Diagram

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B-52 Original Yaw Damper
B-52 Original AFCS
B-52 Longitudinal Control Wheel Steering
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B-58 Stability Augmentation
B-58 Attitude Stabilization Mode

Pitch

B&N SYSTEM

1. Cos \( \theta \)

\[ \text{PITCH SYNCHRO} \]

\[ \text{FILTRATION} \]

\[ \text{PITCH RATE GYRO} \]

\[ \text{WASHOUT} \]

\[ \text{DAMPER SERVO} \]

\[ \text{ELEVATOR A/P SERVO} \]

\[ \text{RATIO CHANGER} \]

\[ \text{AUTO TRIM} \]

\[ \text{MIXER} \]

\[ \text{ELEVON ACTUATOR} \]

\[ \text{ELEVON} \]
B-58 Attitude Stabilization Mode

Lateral
C.S.S. SWITCH

Control Stick Steering Mode

STABILITY AUGMENTATION MODE

ATTITUDE STABILIZATION AND OPTIONAL MODES

B-58 Control Stick Steering Mode
B-58 Mach Mode
B-58 Constant Heading
B-58 Heading Nav Mode
B-58 Automatic Glide Path Mode
B-66 Autopilot

[Diagram showing various components and control systems related to autopilot function, including N-1 Compass System, Localizer Receiver, Static Pressure, Glide Slope Receiver, Position Transmitter, Roll Rate Gyro, Pitch Rate Gyro, Turn Control, and various servos and amplifiers.]

(FC) indicates block functions which are part of the flight controller.

Shaded blocks indicate automatic gain control functions of the airspeed compensator.

[Additional symbols and notes explaining the diagram's components and functions.]
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
- $X_P$: Rotor Position (positive for right pedal forward)
- $K_{\delta y}$: Altitude Gain
- $\dot{\gamma}$: Body Axis Yaw Rate
- $\delta_{\dot{y}}$: Altitude Error (shown at GAIN adapted)
- $\delta_r$: Rudder Deflection
- $\delta_{\dot{r}}$: Rudder Deflection
- $K_g$: Gear Ratio (1 at Gear Up, 4 at Gear Down)
C-5A Pitch Stability Augmentation System

SWITCH POSITION: 1  PITCH AUTOPILOT OFF
                 2  PITCH AUTOPILOT ENGAGED
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: Verhav, Terrain Following and Mach/IAS Modes
Altitude Capture

VSFI $\Delta h$ ft. 
Limiter 7000 FPM

Altitude Hold

R.O.C. $\dot{h}$ ft/sec
CADC
Height Error $\Delta h$ ft

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
C-5A Roll Autopilot: Coursesline and Air-Drop Modes

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C-5A Autothrottle Analytical Diagram
KC-135 Pitch Diagram

KC-135 Lateral-Directional Axis Diagram
XC-142A Pitch Control System Block Diagram
XC-142A Roll and Yaw Control System Block Diagram
XC-142A Collective-Throttle System Block Diagram
E-1B Pitch Axis

K denotes a multiplier constant
$q_c$ denotes airspeed scheduling
CSS denotes control stick steering
S-2D/S-2E Pitch Axis
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
Der. Head. Hold

Norm

$\frac{1}{s}$

Limit

Actuator

$\delta_A$

A/F

$\phi$ (V.G.)

$K_r$

$K_\phi$

$IAS$

Derived Rate

$\frac{s}{(s+40)(s+100)}$

$\frac{1}{s+2}$

$I_0$

$\phi_C$

BQM-34 Roll Axis
K₀ = PITCH CONTROL GAIN = \( \frac{G₀ \cdot G_e}{G_x} \) (deg/deg)

Kₜ = ALTITUDE CONTROL GAIN = \( \frac{Gₜ}{Gₜ} \) (deg/ft)

Note: \( Gₜ \) IS FUNCTION OF \( h₀ \)

(1.e. \( Gₜ = \frac{ΔV}{ΔP} \frac{dp}{dh} |_{h=h₀} \))

MQM-74A Elevator Control System
$K_\phi = \text{ROLL CONTROL GAIN} = G_\phi \frac{G_{\delta_a}}{G_x}$
F3H PITCH CHANNEL
YAW AXIS DAMPER

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

F-86 Pitch-up Preventer
F-89 Sideslip Stability Augmenter
(FC) indicates block functions which are part of the flight controller - WG1229-1

Shaded blocks indicate automatic gain control functions of the airspeed compensator - PG70078-3

(q) 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 CHANNEL

F-100 D/F Autopilot
ROLL CHANNEL

F-100 D/F Autopilot
PITCH DAMPER

- Short Stroke
- Medium Stroke
- Long Stroke

ALARMS:
- Servo Feed Back
- Lead Network
- Non Linear Gain
- Pitch Rate Gyro
- Pitch Rate Transmitter
- Stick Position Transmitter
- Stick Position

NOTE:
- Open when Rudder Pedals are pressed.
- Phase I Configuration
- Quiet Block for Phase I Configuration
- Indicates gain scheduled as a function of airspeed.
- Indicates gain scheduled as a function of airspeed and Mach number.

F-100 D/F Autopilot
(X) INDICATES SIGNAL SUMMING
(■) INDICATES GAIN VARIED AS A FUNCTION OF INDICATED AIR SPEED
(□) INDICATES GAIN VARIED AS A FUNCTION OF TRUE AIR SPEED
(FC) INDICATES PART OF FLIGHT CONTROLLER
--------- DASHED LINE ENCLOSES DAMPER CONFIGURATION BLOCKS

F-101A Autopilot
73
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.

F-101B Autopilot
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
PARALLEL SERVO

Feel System

E-H Valve

Engaged

Servo Ram

Disengaged

Force Switch

System Engage

Hi Pass

P-1013 Stick Pusher
F-102 YAW DAMPER

\[ r \rightarrow 1.25 \text{deg/deg/sec} \rightarrow \frac{\tau s}{\tau s + 1} \rightarrow \delta r(\pm 6') \]

\[ p \rightarrow K_p \rightarrow 0.177 \text{deg/deg/sec} \rightarrow \delta r(\pm 6') \]

\[ \delta_a \rightarrow f(\phi_c) \rightarrow K_{\delta a} \]

\[ f(\phi_c) \rightarrow \frac{0.021 \text{deg/deg/sec}}{Ts + 1} \rightarrow \delta_r(\pm 6') \]

F-102 PITCH DAMPER

\[ \phi \rightarrow K_{\phi} \rightarrow \frac{Ts}{Ts + 1} \rightarrow \text{Series Servo} \rightarrow \text{Elevator} \]
F-105A PITCH CHANNEL
F-105A ROLL CHANNEL
F-105A YAW CHANNEL
MANUAL MODE, YAW DAMPER AND TURN COORDINATOR MODE, ANDAILAS MODE

SUMMING JUNCTIONS

REVERSIBLE

REVERSIBLE

COMPONENTS
OF AIR DATA
COMPUTER

ALL SWITCHES SHOWN IN
DAMPER MODE.
F-111 Pitch Channel Functional Diagram
F-111 Yaw Channel Functional Diagram
F-111 Adaptive Principle
T-38 Stability Augmentation System
AVRO CF-100 Autopilot
There is no Pitch Axis in this autopilot.

NOTE:
There is no Pitch Axis in this autopilot.
Fig. 14. Viggen Pitch Axis Stability Augmentation and Control Stick Steering Mode

Diagram showing flow of signals from various inputs to outputs, including:
- BEEP TRIM COMMAND
- TRIM MOTOR
- LOOP ERROR
- LONGITUDINAL STICK DEFLECTION
- BUNGEE
- MECHANICAL GEARING
- INNER ELEVON SERVO ACTUATOR
- STATIC PRESSURE
- PITOT DIFFERENTIAL PRESSURE
- INNER ELEVON DEFLECTION
- COMMAND MODEL SHAPING
- TO TRIM ACTUATOR
- BODY BENDING FILTER
- SHAPING
- VARIABLE GAIN
- LOW FREQUENCY AUTHORITY LIMIT
- SERVO VALVE
- OUTER ELEVON DEFLECTION
- NORMAL ACCELERATION
- PITCH RATE
- K

Text:
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
GENERAL BLOCK DIAGRAM
FOR ROLL AND PITCH AXES

STICK POSITION
MECHANICAL GEARING

GAIN & MODEL

SHAPING NETWORK
AMPLIFIER & ACTUATOR
ENGINES & FUEL CONTROL
AIRPLANE DYNAMICS

RATE FEEDBACK
ATTITUDE FEEDBACK

SHAPING NETWORK

YAW AXIS
BLOCK DIAGRAM

RUDDER PEDAL POSITION

SHAPING NETWORKS

AMPLIFIER AND SERVO

RATE GYRO
TILT ACTUATOR

1/S
AIRPLANE DYNAMICS
M2-F2 Lateral-Directional Flight Control System
X-15 Roll Axis Configuration
X-15 Yaw Axis Configuration
ELEVATOR CHANNEL

B-707 Autopilot
Federal Specification B-707 Autopilot

**Rudder Channel**

**Notes:**
- **Electrical Link**
- **Mechanical Link**

- Set for maximum static gain, $\frac{I_s}{P}$
  - $I_s = 10 \text{ ft-lb/deg}$
  - $P = \text{deg} / \text{sec}$

- Servo dynamics
  - $I_{330} = \frac{\text{ft-lb}}{\text{deg} / \text{sec}^3}$
  - $T_{\text{load}}$ includes preload, centering spring, control system friction, and aero load ($\text{ft-lb}$)

- Crossfeed from roll channel

- Bandwidth limit, $\frac{1}{\text{sec}}$
BASIC ROLL STABILIZATION

Position Servo

E/M Servo

Tach.

Synch.

ROLL PATH AND NAV MODES

Doppler 

Heading Select

D.G.

Heading Synch.

DC-8 Roll Axis
L-188 Autopilot
L-188 Autopilot
GESAC Pitch Channel (F-4A)
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 (F-4)

NOTE:

\[ \ell_x = 12 \text{ FT} \]

\[ \frac{z_{\delta_e}}{z_{\alpha}} = 0.2 \]
Adaptable FCS Pitch Autopilot Functions (F-4)
Adaptable FCS Lateral/Directional Autopilot Functions
F-4 SPCS Pitch Axis
F-4 SPCS Directional Axis
Switching Logic
\[ SW = C_1 + C_2 + C_3 + \text{SMRD} \dot{\theta}_1 + \text{SMRD} \dot{\theta}_2 \]
\[ V_1 = 1.66V \]
\[ V_2 = 2.42V \]
\[ V_0 = 4.56V \]
BIAS = 30°

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

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<td>0.25 - 1.0</td>
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<td>( K_7 )</td>
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\[ \dot{\theta}_2 \]
0.12 V/Deg/Sec

\[ \dot{\theta}_1 \]
0.12 V/Deg/Sec

\[ K_2 \]

BIAS \( [S + K_3] [S + 50] [S + 50] \)

\[ 0.166 \]

\[ \alpha L_1 \] 0.6V/Deg
\[ \alpha R_1 \] 0.6V/Deg

\[ \alpha L_2 \] 0.6V/Deg
\[ \alpha R_2 \] 0.6V/Deg

\[ K_2 \]

\[ [S + K_3] [S + 50] [S + 50] \]

\[ 0.166 \]

\[ V_0 \]

Pulse Width Modulator

Logic and Switching

To CVU-1

Logic and Switching

To CVU-2

Logic and Switching

To CVU-3

Logic and Switching

To CVU-4

F-4 SFCS Stall Warning
Electrical Back-Up

Signal Selection Device

Channel 2
Channel 3
Channel 4

0.345
S/1000 + 1

3.86

Velocity Sensing Comparator, Shut Off Logic

Channel 4
Channel 3
Channel 2

Secondary Actuator

0.00105 Ns

Figure 12a

Ks

T_m, s + 1

0.567

Figure 12b

K

2.855
Deg

LVDT

1 v/in.

1.26
S/1000 + 1

Demodulator

1 v/in.

1

7.22

LVDT

1 v/in.

S

S + 1

Demodulator

1.1v
S/200 + 1

Note: Dashed lines denote mechanical paths. Solid lines denote electrical paths.

F-4 Survivable Stabilator Actuator Package
F-4 SFCS Adaptive Gain Changer
(a) Pitch channel.

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

Grumman F9F-2 Attitude Command BFW
(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
TWEAD I Lateral-Directional
TREAD II Longitudinal Functional CAS Block Diagram
F-4C TWED II CAS Longitudinal 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)
F-100 Lear Rate Integrating Autopilot
REFERENCES


56. Presentation to ASD Division Advisory Group, General Dynamics/Fort Worth Div., Rept. FZM-12-2357, June 1966.


*U.S. GOVERNMENT PRINTING OFFICE: 1975-635-048/90*