ELEVON DESIGN REVIEW

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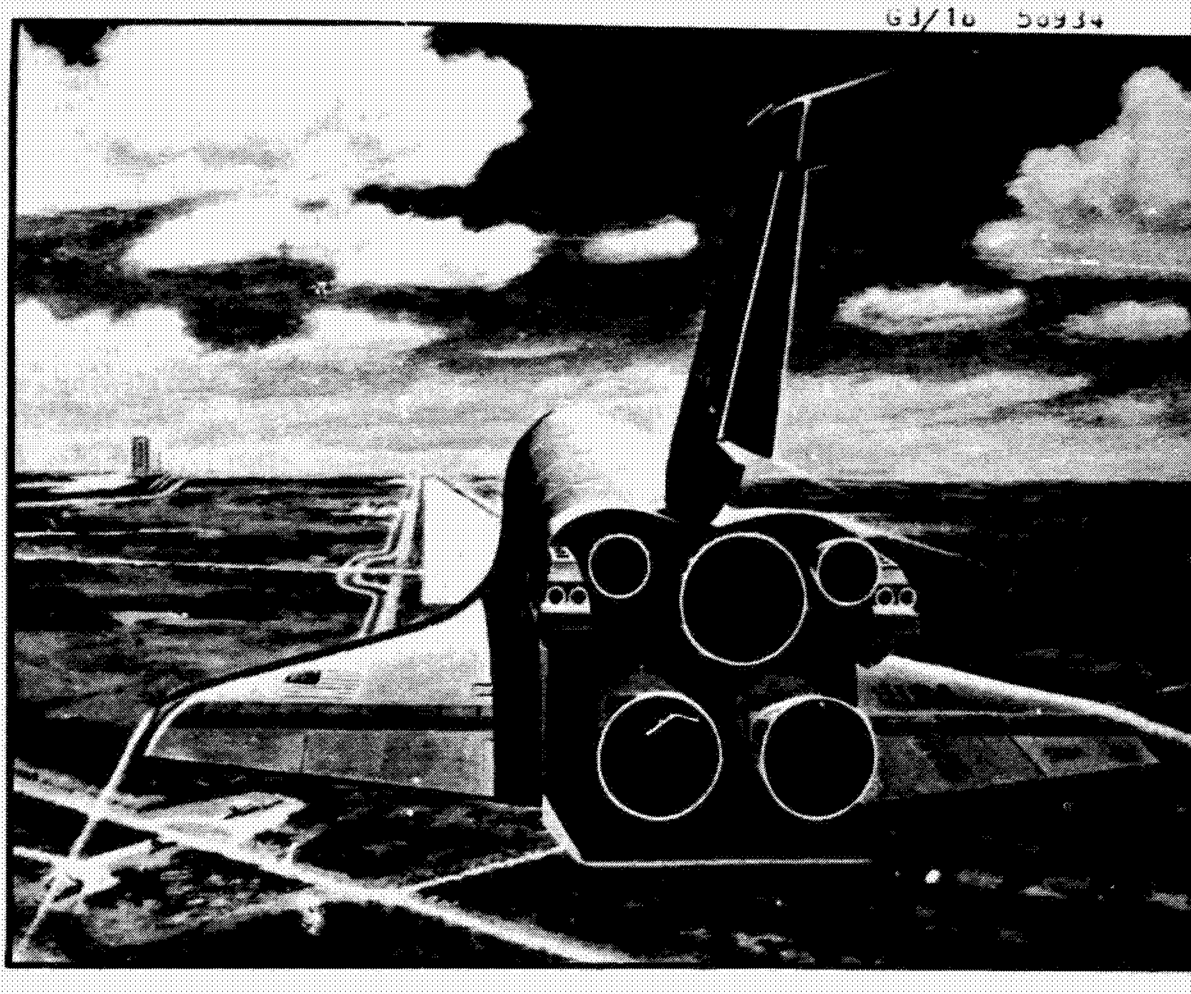

LOCKHEED ELECTRONICS COMPANY, INC.
AEROSPACE SYSTEMS DIVISION
HOUSTON, TEXAS
OCTOBER 1976

JSC-11131

ELEVON DESIGN REVIEW

Job Order 35-479

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
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TECHNICAL REPORT INDEX/ABSTRACT
(See instructions on reverse side.)

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13. ABSTRACT

The document describes the mathematical model implementation of the elevon subsystem for the Shuttle Actuators Simulator (SAS) in the Shuttle Avionics Integration Laboratory (SAIL). The computer subsystem will simulate two outboard and two inboard elevon actuators.

14. SUBJECT TERMS

actuator	simulator	CSMP
mathematical model	flight controls	stiction
elevon	SAIL	Space Shuttle

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FIGURES

LIST OF ABBREVIATIONS, ACRONYMS, AND SYMBOLS

ASA	aerosurface servo amplifier
°C	degrees Celsius
CH	channel
cis	cubic inches per second
CKT	circuit
CMOS	complementary metal oxide semiconducter
deg/sec	degrees per second
EG	Control Systems Development Division (NASA)
EJ	Avionics Systems Engineering Division (NASA)
°F	degrees Fahrenheit
F/B	feedback
FET	field effect transistor
FS	full scale
GND	ground
H	henry
Hz	hertz
IC	initial condition
in	inch
ISO	isolation
J-box	junction box
lb	pound
LEC	Lockheed Electronics Company, Inc.
LVDT	linear variable differential transformer
mA	milliampere

MDM	multiplexer/demultiplexer
mH	millihenry (1×10^{-3} henry)
mV	millivolts (1×10^{-3} volts)
PC	printed circuit
pF	picofarad (1×10^{-9} farad)
POS	position
PRI	primary
rad	radian
REF	reference
rms	root-mean-square
SAIL	Shuttle Avionics Integration Laboratory
SAS	Shuttle Actuators Simulator
S/C	signal conditioner
SDS	Shuttle Dynamics Simulator
sec	second
SEC	secondary
SW	switch
TBD	to be determined
TOC	Test Operations Center
TTL	transistor-transistor logic
V	volts
Vac	volts alternating current
VDS	Vehicle Dynamics Simulation
XDUCER	transducer
ΔP	delta pressure
ΔP_p	delta pressure primary

ΔP_s	delta pressure secondary
Ω	ohms

1. INTRODUCTION

1.1 PURPOSE

This document presents the design of the elevon subsystem for the Shuttle Actuators Simulator (SAS). This simulator will replace the elevon actuator hardware in the Shuttle Avionics Integration Laboratory (SAIL). It will consist of four elevon actuators.

1.2 SCOPE

The scope of this document encompasses all technical aspects for the elevon subsystems. See figure 1-1. It details interface design, signal characteristics, and system performance. Nontechnical requirements are introduced where required to aid in comprehension.

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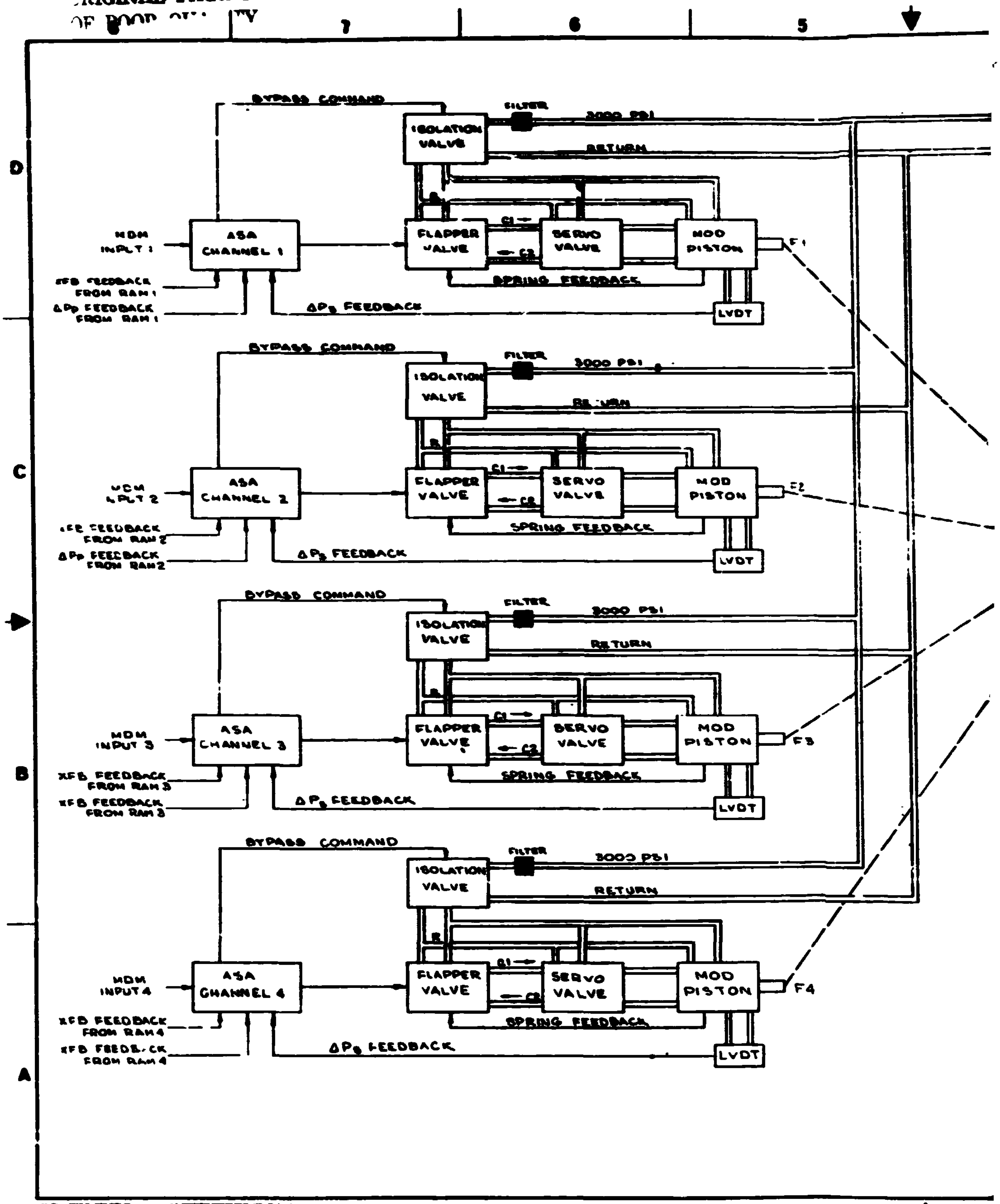

Figure 1-1. – Functional block diagram o
Shuttle Actuators S

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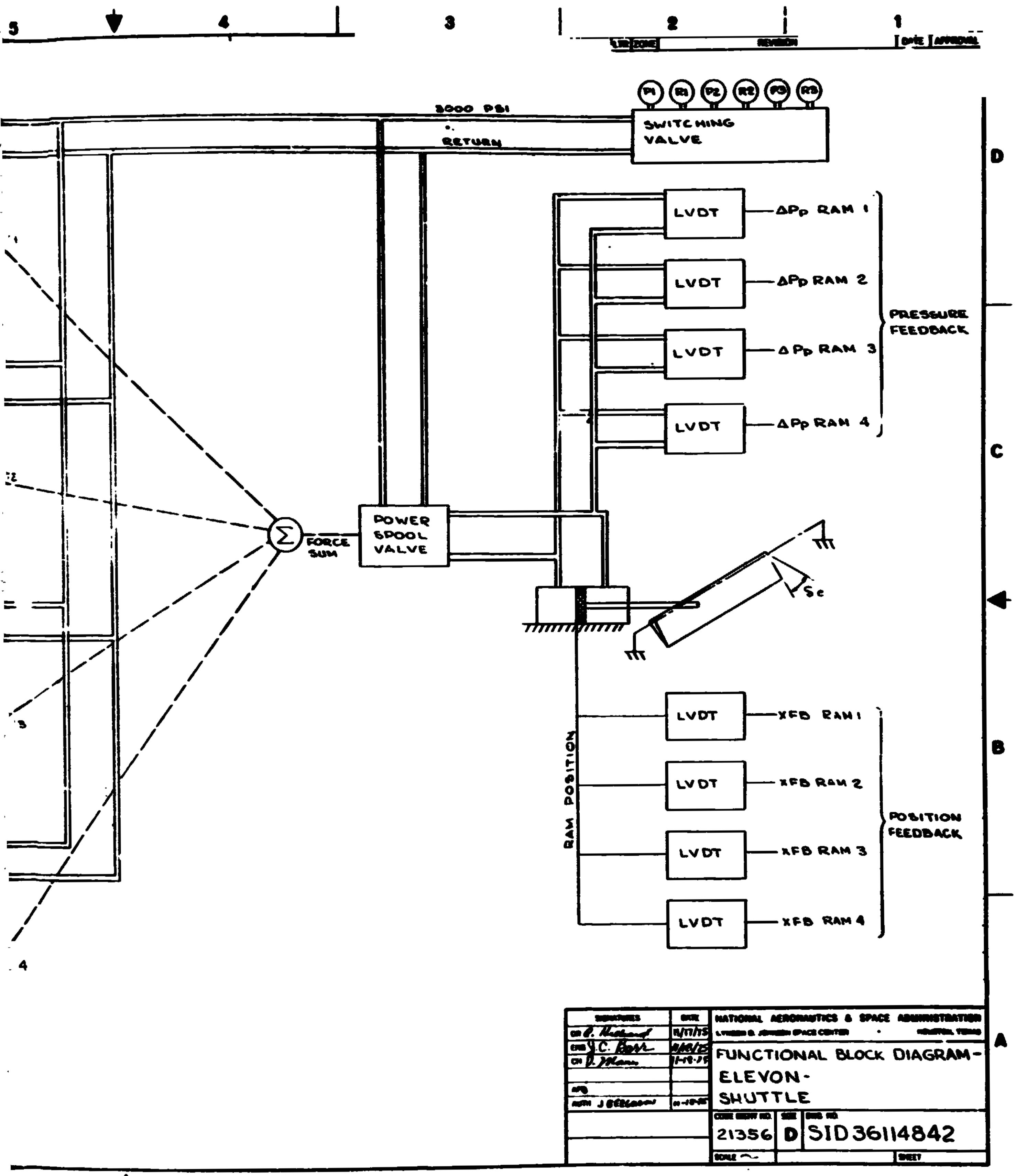

block diagram of the elevon subsystem for the
:tle Actuators Simulator.

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2. MATHEMATICAL MODELS

2.1 DEFINITION OF MATHEMATICAL MODELS

Four mathematical models are to be used. Two are from Rockwell International document SD74-SH-0324A, *Descriptions and Mathematical Models of Aerosurface Actuators*, September 1975. Associated material is presented in tables 2-I, 2-II, and 2-III.

2.1.1 FULL-UP MODEL

The full-up model that is assumed to be complete and representative of the hardware is shown in figure 2-1 and is identified as model 1 in the Rockwell document. The implementation of this model on the IBM-360 computer defines the baseline data for the simulator correlation and checkout.

2.1.2 TOLERANCE MODEL

The tolerance model which defines the minimum acceptable standard of performance is shown in figure 2-2 and is identified as model 2 in the Rockwell document. It defines the tolerance data for the elevon simulator correlation and checkout.

2.1.3 IMPLEMENTATION MODEL

The implementation model in figure 2-3 is to be mechanized in simulator hardware. Its performance is between the full-up and the tolerance models and has been implemented on the IBM-360 computer.

2.1.4 MECHANIZATION MODEL

The physical constants for the mechanization model have been resolved into resistor ratios. This model is suitable for direct implementation on an analog computer.

2.1.5 PARAMETERS

The inboard and outboard elevon models differ only in the value of physical constants. All temperature sensitive constants used in the mathematical models were selected at the 100° F value. Table 2-IV is a list of the values of the constants used and their class designations. The elevon constants are divided into three classes by anticipated adjustment probability. The classifications are referred to as A, B, and C. The classifications correspond to:

- Class A — Those parameters recognized as likely to change and, as such, are mounted on readily accessible and removable socket connectors as shown in figure 2-4.
- Class B — Those parameters recognized as unlikely to change but may do so under unusual conditions or circumstances. These will be permanently soldered onto the printed circuit (PC) board assemblies.
- Class C — Those parameters defined as definitely unchanging and whose values are fixed. These could be elements of a transfer function buried in circuitry, constants lumped together, or potted modules. Changes to these would likely require major circuit design and/or layout revisions.

The plan is to keep the number of class A components at a minimum and maximize the number of components into classes B or C.

2.2 MODEL IMPLEMENTATION VERIFICATION

2.2.1 FULL-UP MODEL

It is assummed that this model represents the hardware accurately. The program output will be compared with the hardware design specification in Rockwell International documents. Four tests were run to verify the computer implementation:

- Actuator stroke limits were compared to table III page 14, Rockwell International document MC621-0014.

- Velocity gain was compared to the gain requirements in figure 5 and table 2 of Rockwell International document 392-200-75-340 for actuator loads of 0, 2×10^4, and 3.945×10^4.
- Gain-phase frequency response data were compared to the data of figure 4 of Rockwell International document 392-200-75-340.
- The step response was compared to figure 05.10-2 of Rockwell International document ML0101-0001-005, sheet 3 of 185, Rev. A-01.

2.2.2 IMPLEMENTATION MODEL

This model is verified by three tests:

- Actuator stroke limits were compared to model 1.
- Gain-phase frequency response data were compared to model 1.
- Step response locus comparisons were made to model 1 for δ_e, $\dot{\delta}_e$, I, X_{PS}, Q_L, P_S, and P_L.

2.2.3 MECHANIZATION MODEL

The control valve was implemented on an Astrodata CI-175 general-purpose, analog computer. The step response, shown in figure 2-5, was compared to model 1.

TABLE 2-I. – ELEVON SCALING FACTORS

Factor	Variable	Units	Inboard	Outboard
K1	I	mA	8.60	8.60
K2	X_{FL}	in	0.0016	0.0016
K3	X_S	in	0.015	0.015
K4	F_I	lbs	579.0	579.0
K5	$\dot{X}_{PS}$	in/sec	62.0	62.0
K6	X_{PS}	in	0.065	0.065
K7	P_{VS}	psi	3000.	3000.
K8	P_V	psi	3000.	3000.
K9	P_L	psi	3000.	3000.
K10	—	—	—	—
K11	Q_L	in^3/sec	400.0	180.0
K12	P_I	psi	3000.	3000.
K13	—	—	—	—
K14	—	—	—	—
K15	T_{TOT}	in-lbs	1.0×10^6	5.0×10^5
K16	F_L	lbs	65400.	54060.
K17	T_R	in-lbs	1.0×10^6	5.0×10^5
K18	TAERO	in-lbs	1.0×10^6	5.0×10^5
K19	$\dot{\delta}_e$	deg/sec	100.	100.
K20	δ_e	deg	36.5	36.5
K21	X_R, X_{STR}	in	7.320	4.266
K22	X_{FB}	in	7.320	4.266
K23	V_{PL}	volts	5.000	5.000
K24	V_{XFB}	volts	5.000	5.000
K25	V_{CI}	volts	5.000	5.000
K26	M_R	in	15.10	8.80

TABLE 2-II. – ELEVON MODEL NONLINEARITIES (NL)

NL*	Description	Value	Units
A	Servo Amplifier Current Limiter	±8.6 ± 1.0	mA
B†	Torque Motor Hysteresis (Full Band)	0.029	mA
C	Torque Motor (Nozzle) Stroke Limite	±0.0016	in
D	Second Stage Friction (Stiction)	0.20	lb
E	Second Stage Spool Stroke Limit	±0.015	in
F	Mod Piston Friction (Stiction), Total/Per Channel		
	Four Channels Active	11.6/2.9	lb
	Three Channels Active, One Bypassed	12.5/4.17	lb
	Three Channels Active, One Hardover	40.2/13.3	lb
	Three Channels Active, One at Null/Open	40.2/13.3	lb
	Two Channels Active, Two Bypassed	12.4/6.2	lb
G	Power Spool Stroke Limit	±0.065	in
H	Power Ram Friction (Stiction), Inboard	$1470.R(\delta_E)$	in-lb
	Outboard	$1452.R(\delta_E)$	in-lb
J	Pressure Transducer Hysteresis (Full Band)	62.5	psi
K	Elevon Seal Panel Friction (Stiction)	15000.	in-lb

*These letters correspond to the letters circled in figures 2-2 and 2-3.

$$^{\dagger}B = 0.02 + \left(\frac{0.16 \pm 0.06}{7.6}\right) I$$

NOTE: Assume a running (coulomb) friction magnitude at 1/3 of Stiction value.

TABLE 2-III. – ELEVON MODEL CONSTANTS

Constant	Description	Inboard 100° F	Outboard 100° F	Units
A_R	Ram Piston Area	21.80	18.02	in^2
D_E	Elevon Viscous Damping (Mechanical)	45000.	15000.	in-lb-sec
I_E	Elevon Inertia About Hinge Line	9473.	2663.	in-lb-sec^2
K_B	Flow Force (Bernoulli) Coefficient	0.755	0.319	in
K_{FB}	Actuator Position Transducer Gain (LVDT)	0.683	1.173	V/in
K_{QPS}	Power Spool Flow Gain	124.7	51.8	$in^3/sec\sqrt{lb}$
K_S	Local Structural Stiffness External to Actuator	298000.*	154000.*	in/lb
K_T	Total Actuation System Stiffness	177446.	128583.	lb/in
K_0	Pressure Loss Constant	7.67	4.24	psi
K_1	Linear Pressure Loss Coefficient (Primary Valve)	0.10756	0.16476	psi/cis
K_2	Quadratic Pressure Loss Coefficient (Primary Valve)	0.01765	0.05228	psi/cis^2
K_{12}	Linear Pressure Loss Coefficient (Second Stage Valve)	0.0922	0.1494	psi/cis
K_{22}	Quadratic Pressure Loss Coefficient (Second Stage Valve)	0.00997	0.0446	psi/cis^2
V_R	Total Effective Volume of Ram Cylinder	337.1	165.1	in^3

*Nominal value (tolerance range = 60% to 150% nominal)

TABLE 2-IV. – ELEVON PARAMETERS

Constant	Program name	Description	Value	Units	Parameter class
A_C	AC	Area, ΔP Feedback Piston	0.008975	in^2	C
A_P	AP	Area, Second Stage Spool	0.02761	in^2	C
A_{PS}	APS	Area, Mod Piston	0.1930	in^2	C
β	BETA	Hydraulic Fluid Bulk Modulus	171700.	psi	C
B_P	BP	Viscous Damping, Second Stage Spool	0.0648	lb-sec/in	B
B_{PS}	BPS	Viscous Damping Mod Pistons and Power Spool	1.386	lb-sec/in	B
C1	C1	Flow/Displacement Characteristics, Nozzle	185.2	in^2/sec	B
C_L	CL	Power Spool Laminar Leakage Flow Coefficient	1.08×10^{-8}	in^6/lb-sec	B
C_Q	CQ	Second Stage Flow Gain Coefficient	4.59	in^3/sec $\sqrt{lb}$	B
C3	CTH	Flow/Pressure Characteristic, Fixed Restriction	0.0000876	in^5/lb-sec	B
C2	CTW	Flow/Pressure Characteristic, Nozzle	0.1096	in^4/lb-sec	B
K_A	KAMP	Servo Amplifier Position Error Gain	15.0	mA/V	C
K_C	KC	Dynamic Load Damping Gain	1.71	mA/V	B
K_δ	KL	Elevon Aerodynamic Spring Rate	$0 \rightarrow 2. \times 10^{-6}$	in-lb/rad	C
K_N	KN	Nozzle Pressure Feedback Constant	0.000138	in-lb/psi	B
K_P	KP	Spring Rate, Second Stage Spool (total)	1200.	lb/in.	C
K_{PS}	KPS	Secondary Pressure Feedback Gain (Model 2 only)	7.479×10^{-6}	in-lb/psi	C
K_{PT}	KPT	Pressure Transducer Gain	0.00167	V/psi	B
K_{QS}	KQS	Secondary Flow Gain Coefficient (Model 2 only)	4.9769	in^3-lb$^{3/2}$/sec	C
K_{TM}	KTM	Torque Motor Gain	0.045	in-lb/mA	A
K_{XPS}	KXPS	Wire Feedback Gain, Mod Piston to Torque Motor	6.22	in-lb/in	B
L	L	Power Spool Overlap	0.001	in	C
L_{AP}	LAP	Power Spool Effective Overlap	0.00118	in	B
ζ_D	LD	Demodulator Filter Damping Factor	0.707	—	C
L_N	LN	Effective Torquer Inverse Stiffness	0.01693	in/in-lb	B
M_P	MP	Mass, Second Stage Spool	0.0000683	lb-sec^2/in	C
M_{PS}	MPS	Mass, Mod Pistons and Power Spool (total)	0.00207	lb-sec^2/in	C
P_{SS}	PSS	Supply Pressure to Actuator (nominal)	3000.	psi	A
R_{CL}	RCL	Power Valve Spool/Sleeve Radial Clearance	0.0000475	in	C
τ_{DT}	TDT	LVDT Time Constant	0.004	sec	C
V_1	V	Nozzle Spool Volume (both sides)	0.0838	in^3	C
V_{T2}	VT	Mod Piston Effective Volume (total)	0.62	in^3	C
ω_D	WD	Demodulator Filter Natural Frequency	314.	rad/sec	C
X_o	XO	Flapper-Nozzle Spacing	0.00185	in	C
X_{PSL}	XPSL	Power Spool Maximum Travel	0.065	in	C
τ_{XS}	TXS	Second Stage Time Constant	0.002	sec	C

Note: Adjust B_E and I_E for δ_e in degrees (÷57.3)

$$K_{QS} = \frac{2C_1(A_P - A_C)}{K_P(C_2X_o + C_3)} = 19.8099 \qquad B_E = 261.799 \frac{\text{in-lb}}{\text{deg/sec}}$$

$$K_{PS} = \frac{A_C}{K_P} = 7.4791 \times 10^{-6} \qquad I_E = 46.4781 \frac{\text{in-lb}}{\text{deg/sec}^2}$$

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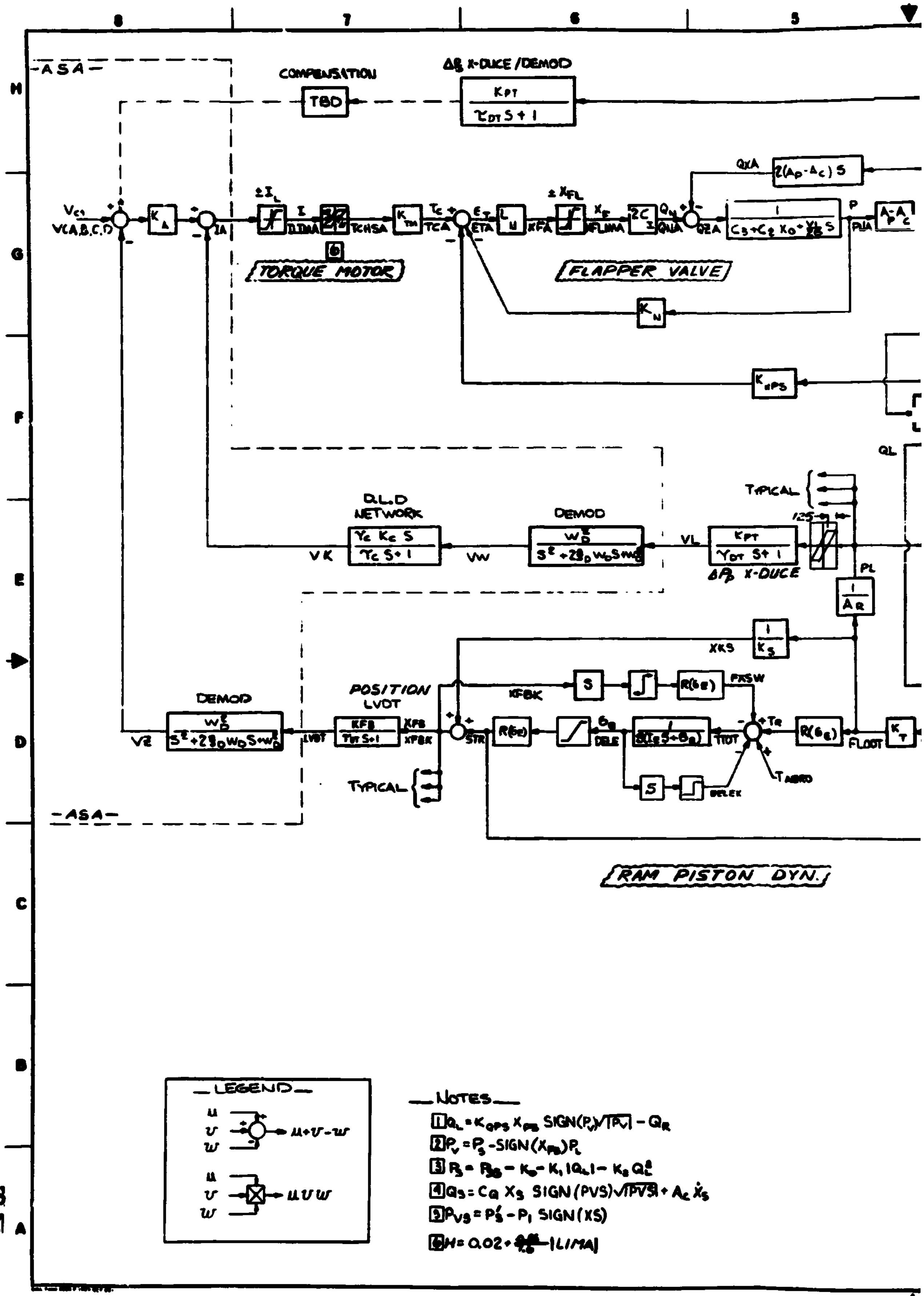

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Figure 2-1. – F

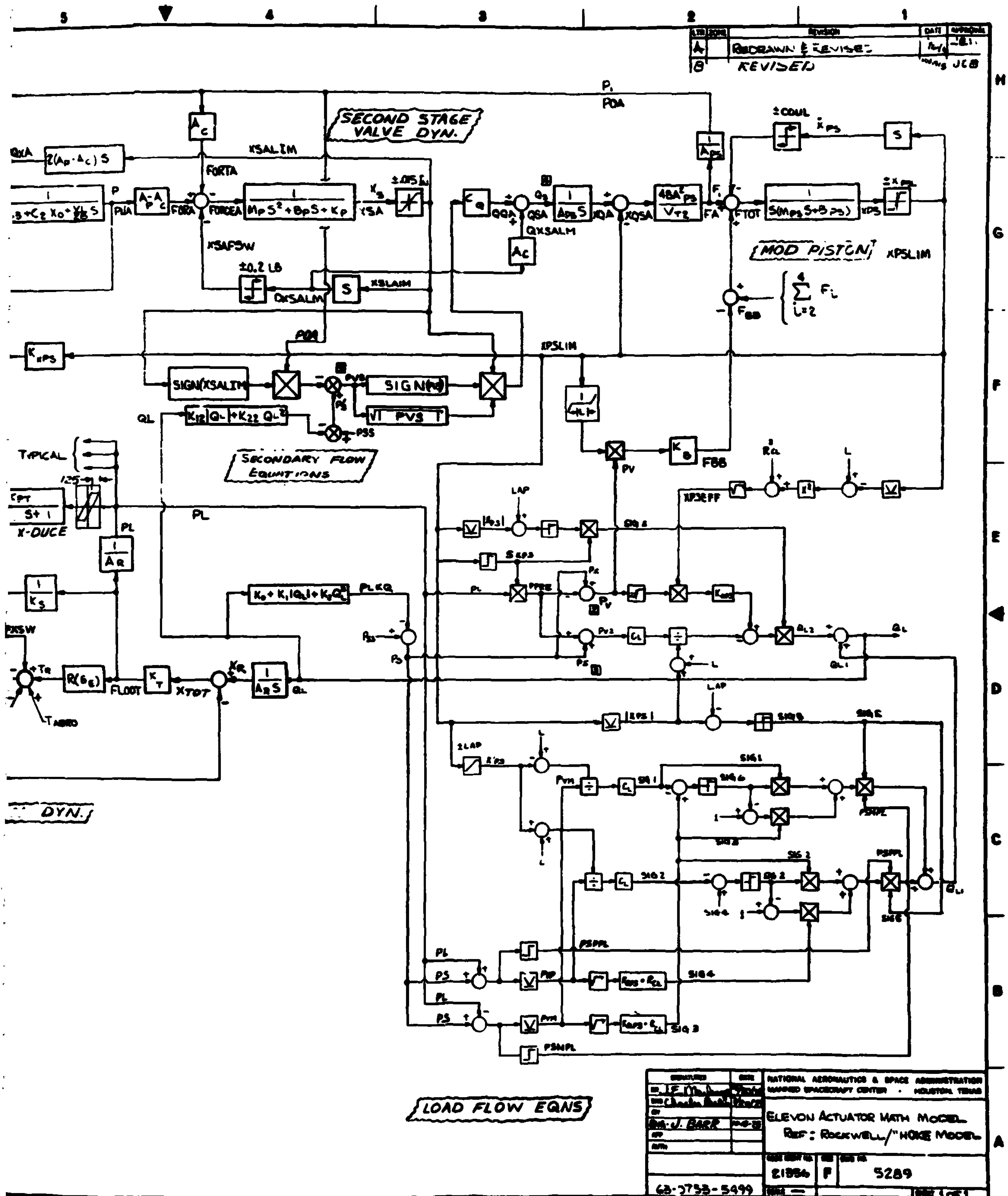

Figure 2-1. — Full-up model.

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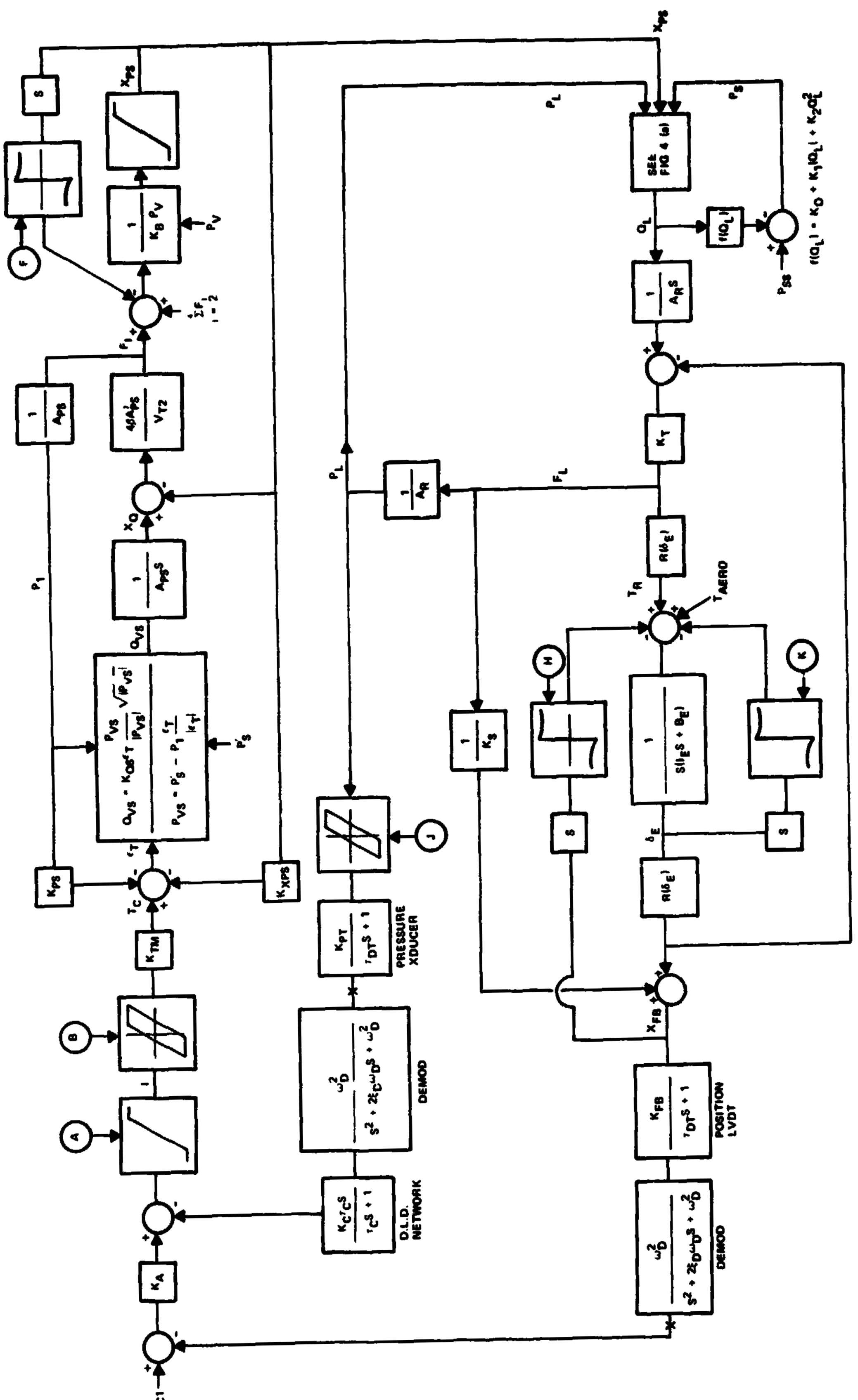

Figure 2-2. — Simplified elevon control system (model 2).

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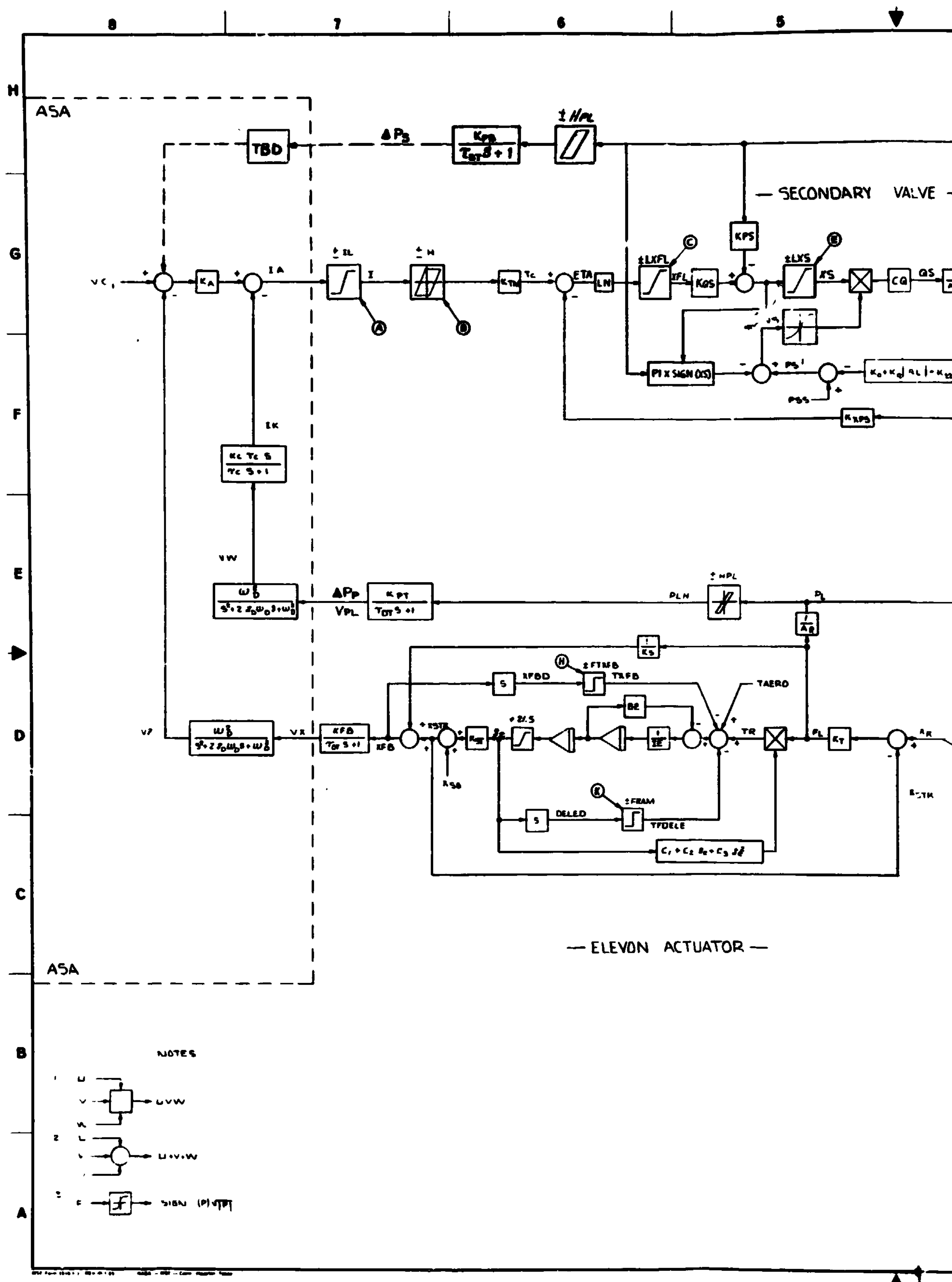

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Figure 2-3. – Implement

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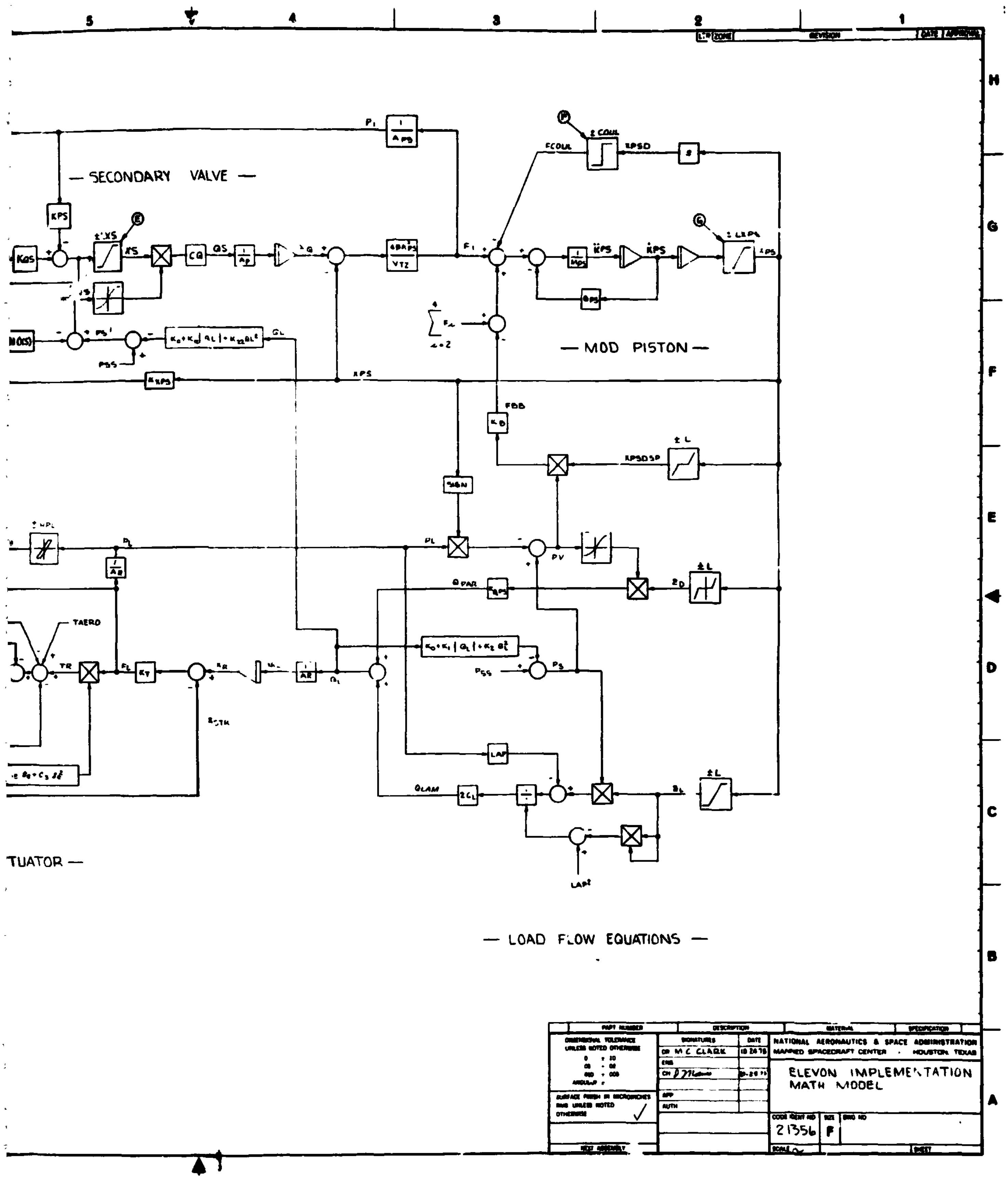

Figure 2-3. – Implementation model.

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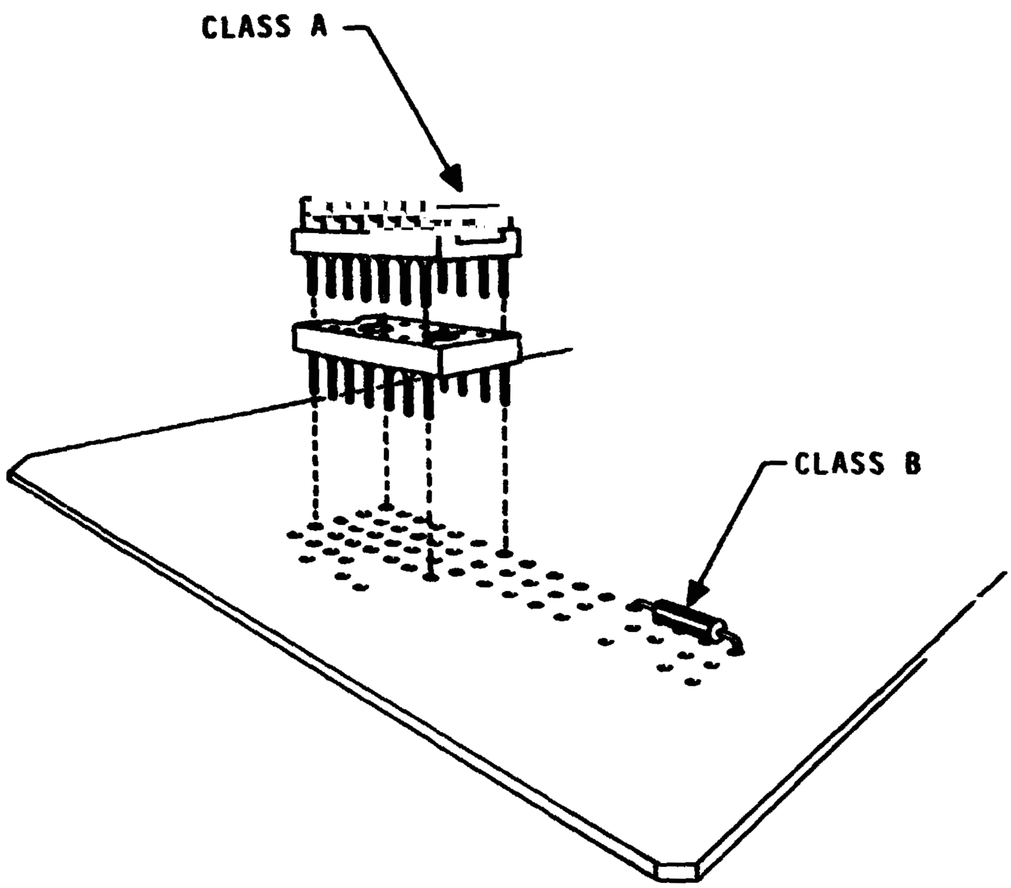


Fi:.re 2-4. – Class A and B components.

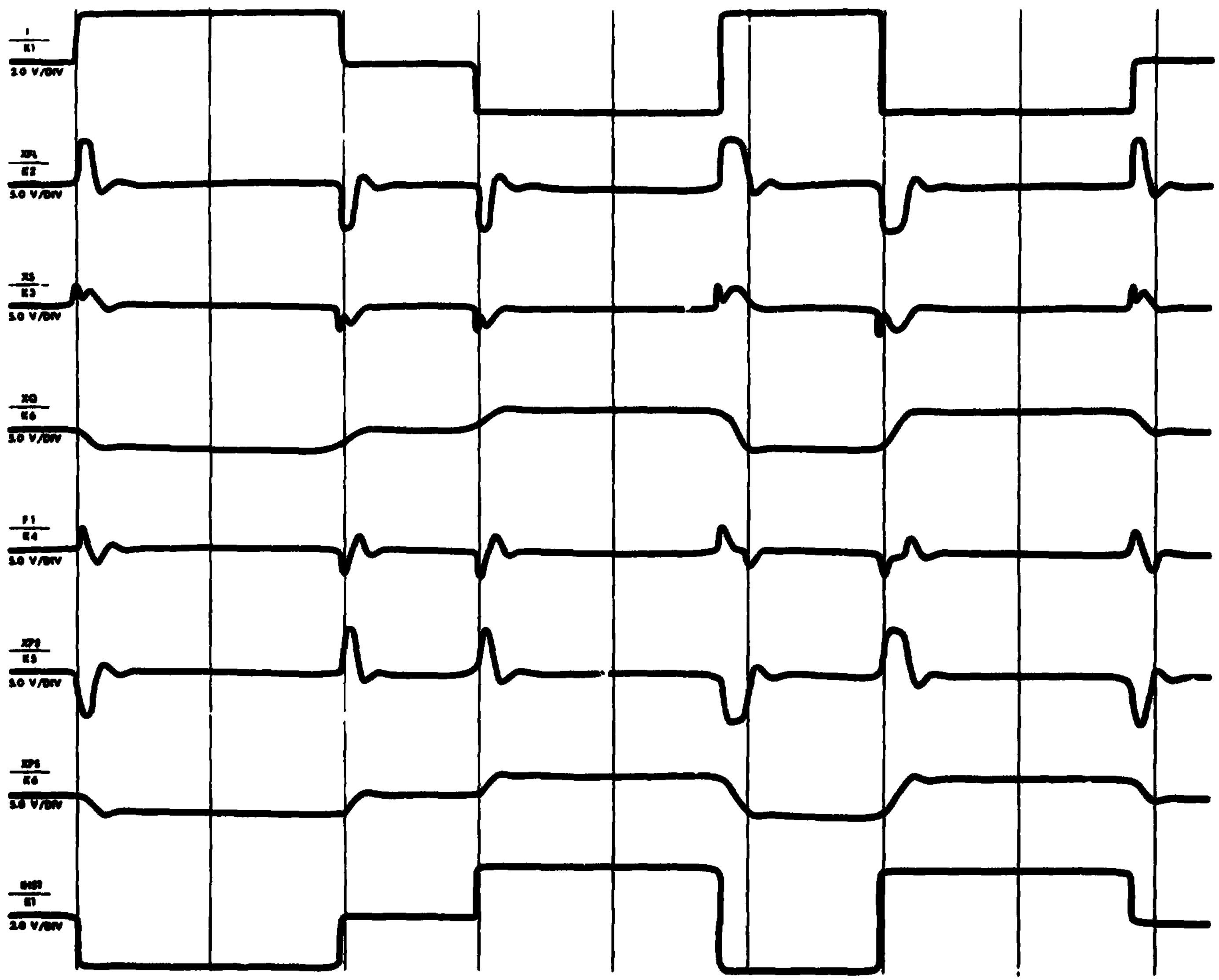


Figure 2-5. — Mechanization verification.

3. INTERFACE REQUIREMENTS

The four interfaces that have been established for the SAS are shown in figure 3-1. These are the interfaces between the SAS and the Shuttle Dynamics Simulator (SDS), between the SAS and the Test Operations Center (TOC) (via J-box 3), between the SAS and the Aerosurface Servo Amplifier (ASA), and the checkout interface which is used for functional checkout and maintenance. The cables required to complete these interfaces are shown in figure 3-2.

3.1 GENERAL REQUIREMENTS FOR BUFFERING

3.1.1 OUTPUT SIGNALS

All SAS output signals except ASA-related signals will be buffered by isolation amplifiers. All output from the SAS to the ASA will be transformer isolated.

3.1.2 INPUT SIGNALS

All SAS input signals except ASA-related signals will be buffered by differential amplifiers or by optical isolators. All SAS inputs from the ASA will be buffered by differential amplifiers, optical isolators, or transformer coupling.

3.1.3 GROUNDS

No external signal grounds will be referenced within the subsystem. All signal ground paths will be isolated by appropriate devices to prevent any ground connection within the subsystem. One and only one ground reference within the subsystem unit will be brought out of the chassis. This ground point in the subsystem unit will be available for reference to the SAIL single-point ground. The equipment ground reference will be connected to the SAS chassis. See figure 3-3.

3.2 ASA/SAS INTERFACE

3.2.1 GENERAL DESIGN

This section outlines the general systems design of the interface. The detailed circuits are presented in section 7, Detailed Circuit Design.

3.2.2 CONNECTORS

The interface for the ASA/SAS will be four 66-pin connectors. There is one connector arranged to connect directly into the back of each elevon chassis. See figure 3-4.

3.2.3 SIGNALS REQUIRED

See figure 3-5.

- Input

  Servo valve – four required
  Isolation solenoid – four required
  Excitation 400 Hz 26 Vac – eight required

- Output

  Position transducer – four required
  ΔPs differential pressure transducer – four required
  ΔPp differential pressure transducer – four required

3.2.4 SIGNAL CHARACTERISTICS

- Input

  Servo valve – 1100 ohms (Ω) and 6.0 henrys (H) inductance and 3300 picofarads (pF) capacitance in parallel. See figure 3-6.

  Isolation solenoid – 75 Ω and 400 millihenry (mH) inductance in parallel with 3300 pF capacitance. See figure 3-7.

- <u>Output</u>

  Position transducer – Position transducer output is transformer isolated from SAS subsystem and is a 400 Hz amplitude modulated signal. Reference will be from the ASA 400 Hz excitation power. Null voltage will be 100 mV rms or less and phase shift between excitation and output will be ±6° maximum. See figure 3-8. Phasing is positive for trailing edge down.

  Differential pressure transducer – Differential pressure transducer output is transformer isolated from SAS subsystem and is a 400 Hz amplitude modulated signal. Reference will be from the ASA 400 Hz. Null voltage will be 100 mV rms or less and phase shift between excitation and output will be ±6° maximum. See figure 3-9.

3.3 J-BOX 3/SAS INTERFACE

3.3.1 SIGNALS REQUIRED

- <u>Input</u>. There will be an analog initial conditions (IC) signal which will be generated in the TOC. This signal will be used to control the signals δ_E and X_{FB} for each elevon subsystem. There will also be a discrete input which will cause an integrator in each elevon actuator subsystem to switch from "IC" to "Operate." There will also be two fault lines from TOC to the SAS which will cause insertion of fault conditions in the SAS. Fault insertion is discussed in section 4, and initialization is discussed in section 6.

- <u>Output</u>. There will be four rate signals, one from each elevon sent to the TOC via J-box 3. There will be four position signals, one from each elevon, sent to the TOC via J-box 3. See figure 3-10. These will be analog signals with 0 to 5 V amplitude.

3.3.2 SIGNAL CHARACTERISTICS

- Input. All discrete inputs will be transistor-transistor logic (TTL) levels capable of driving or sinking 25 mA. See figure 3-11. All analog inputs will be 0 to 5 V nominal with ±15 maximum input voltage at the SAS. All analog input signals will be via differential amplifiers as shown in figure 3-12.
- Output. All analog signals will be via an isolation type amplifier to prevent ground loops.

3.4 SDS/SAS INTERFACE

3.4.1 SIGNALS REQUIRED

3.4.1.1 Position Signal

A position signal from each elevon is required for use in the SDS. The panel positions are labeled δ_{ELO}, δ_{ELI}, δ_{ERI}, and δ_{ERO}. See figure 3-13.

3.4.1.2 Acceleration Signals

Four acceleration signals are required. These are the four elevon panel accelerations – $\ddot{\delta}_{ELO}$, $\ddot{\delta}_{ELI}$, $\ddot{\delta}_{ERI}$, and $\ddot{\delta}_{ERO}$. See figure 3-13.

3.4.1.3 Hinge Moment

SDS will provide a return signal to SAS which is proportional to the hinge moment for each elevon – M_{HERO}, M_{HERI}, M_{HELI}, and M_{HELO}. See figure 3-13.

3.4.1.4 Simulated Hydraulic Pressure

An internally generated adjustable reference voltage will be used to set the system hydraulic supply pressure; however, provisions will be made for the elevon subsystem to accept an external voltage proportional to the system hydraulic supply pressure. See figure 3-14.

3.4.2 SIGNAL CHARACTERISTICS

All input and output signals will comply with paragraph 3.1, *General Requirements for Buffering.*

- Input. All analog input from the SDS will be ±10 V nominal amplitude with ±15 V maximum amplitude at the SAS interface.
- Output. All analog signals output from the subsystem units for use in the SDS will be ±10 V nominal amplitude with ±15 V maximum amplitude.

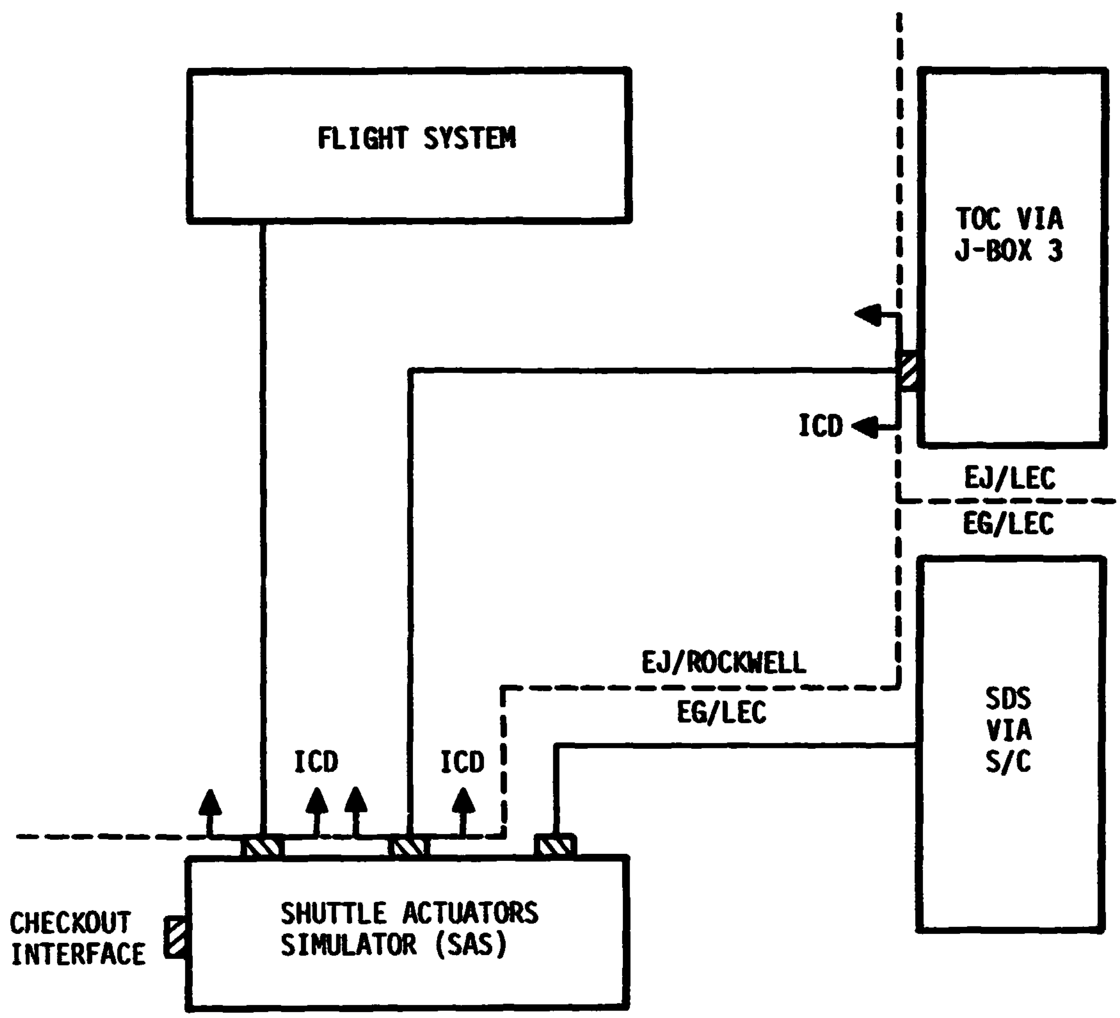
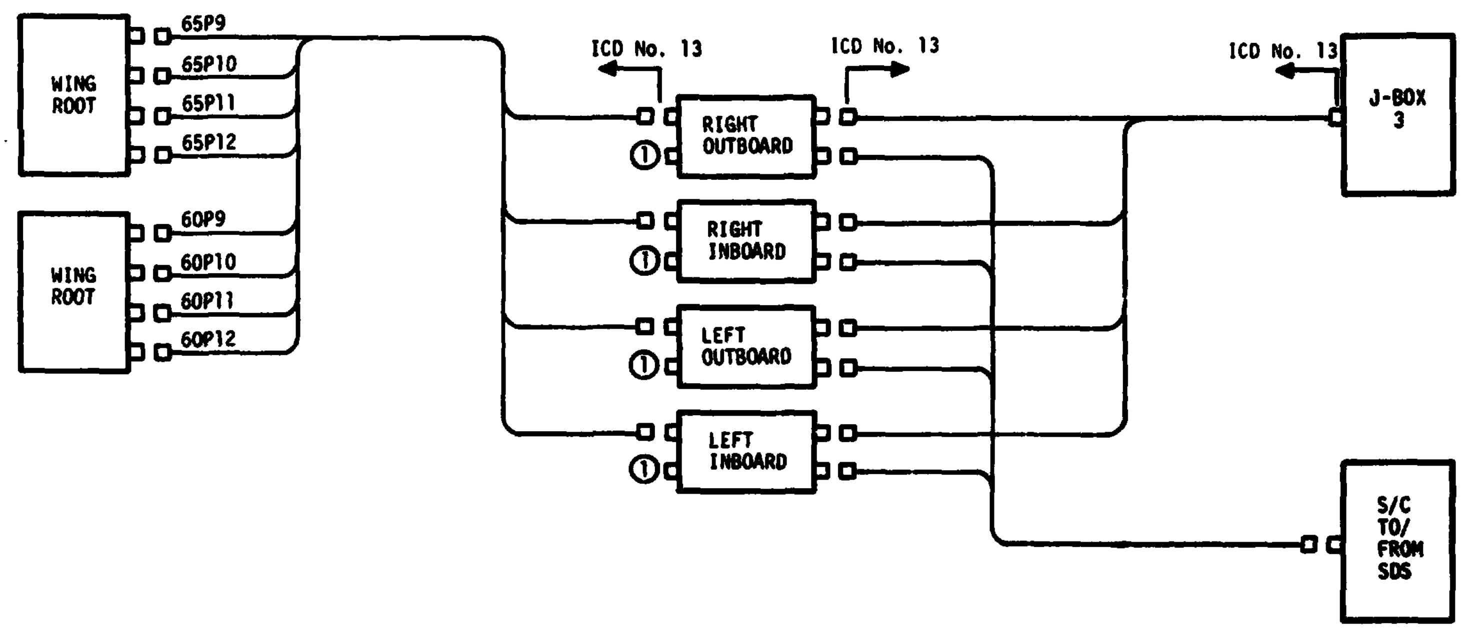


Figure 3-1. – Overall interface diagram.



NOTES: 1 TEST CONNECTOR

Figure 3-2. — Cable requirements.

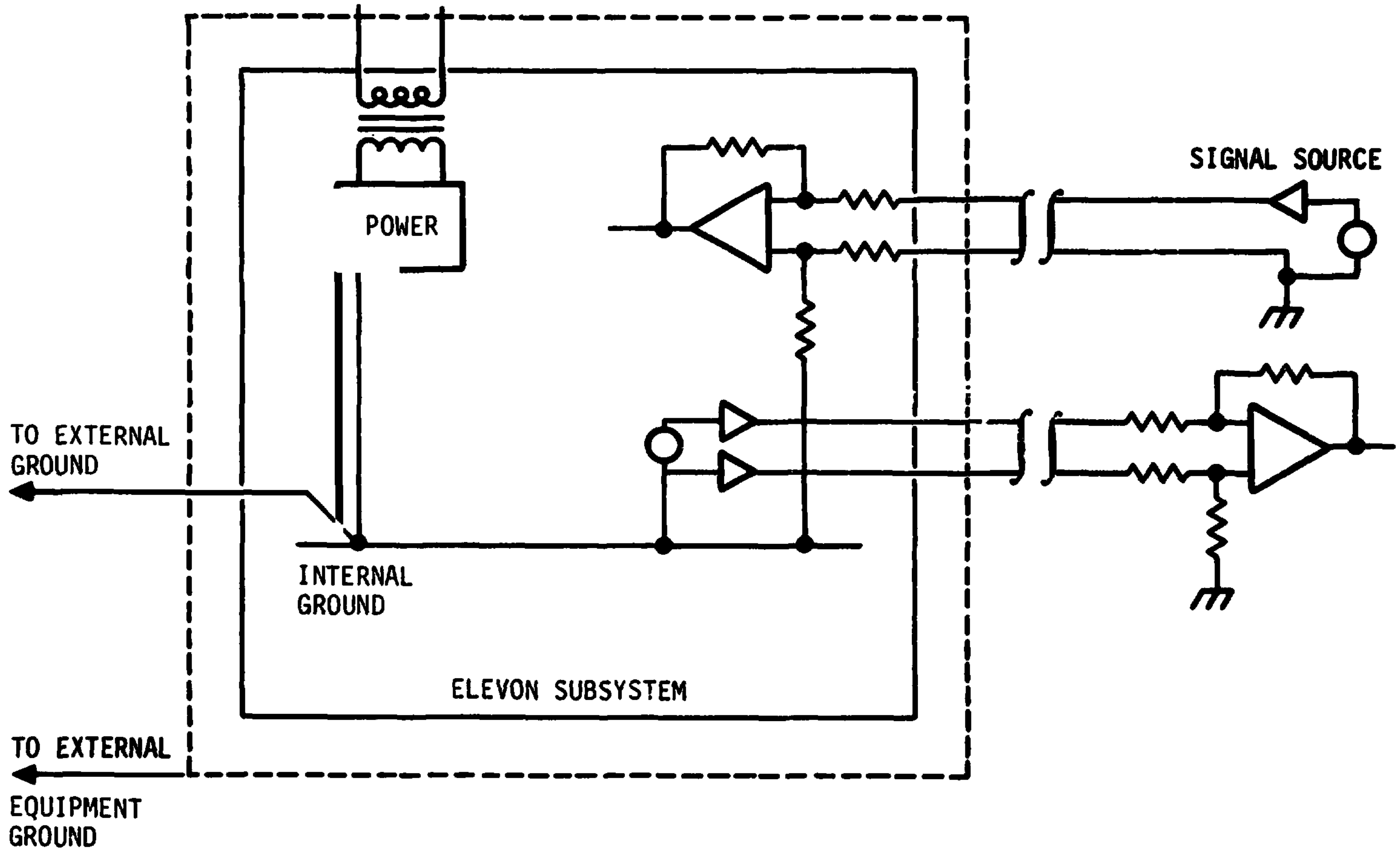


Figure 3-3. — Grounding.

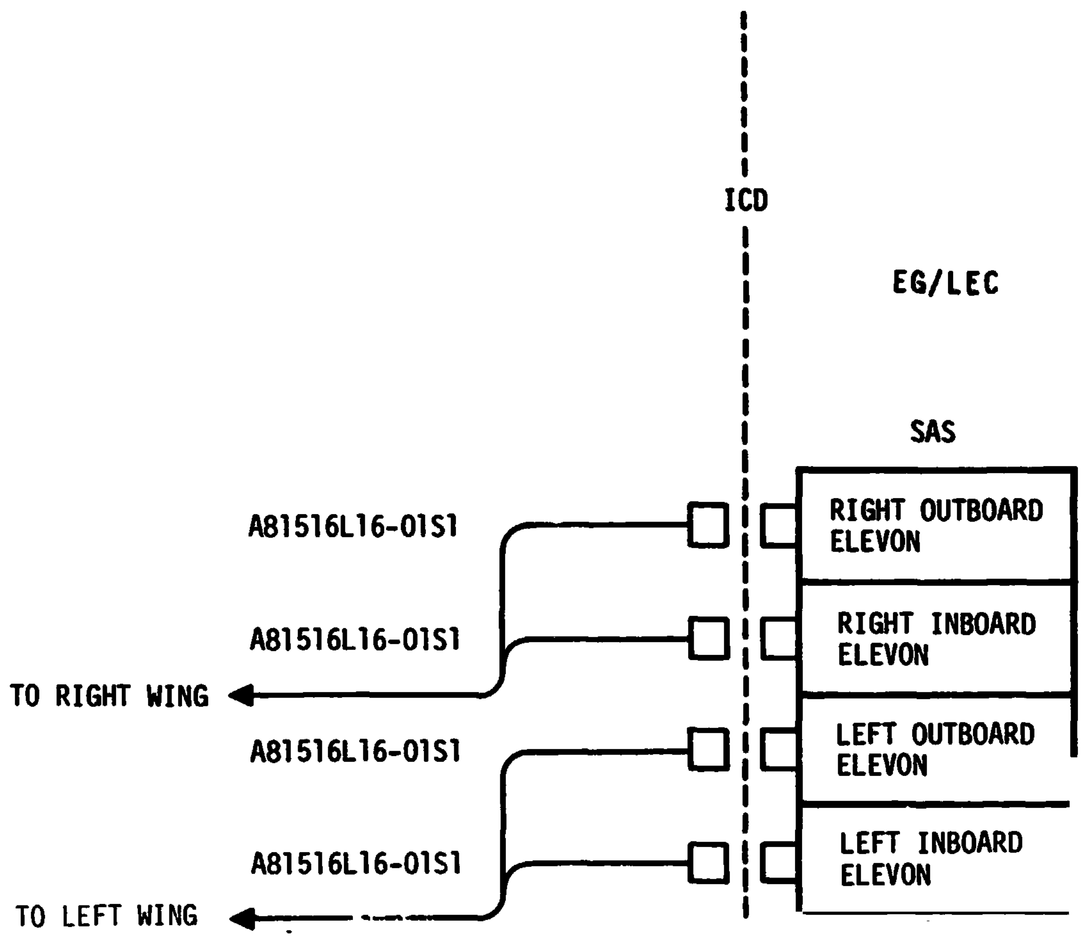


Figure 3-4. – ASA/SAS interface (connectors).

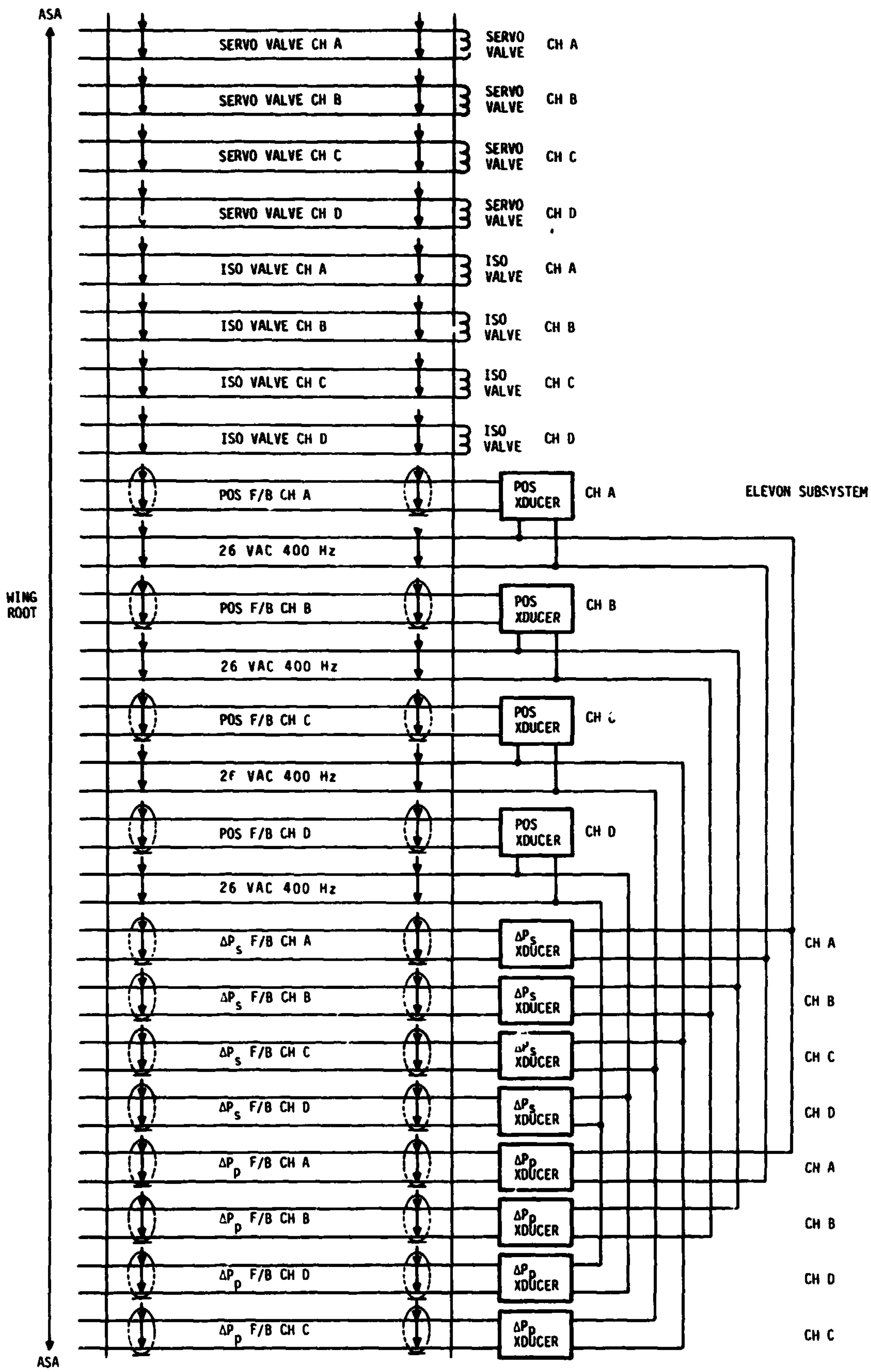


Figure 3-5. — Elevon actuator subsystem.

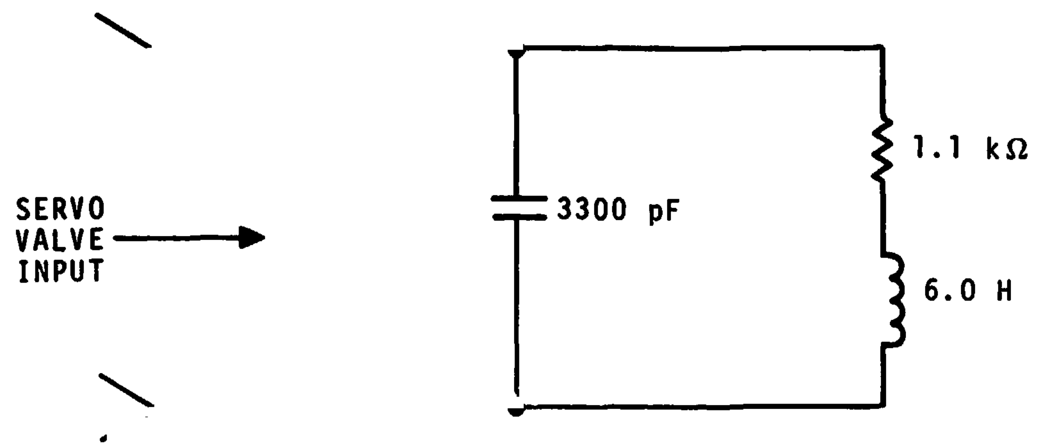


Figure 3-6. – Servo valve.

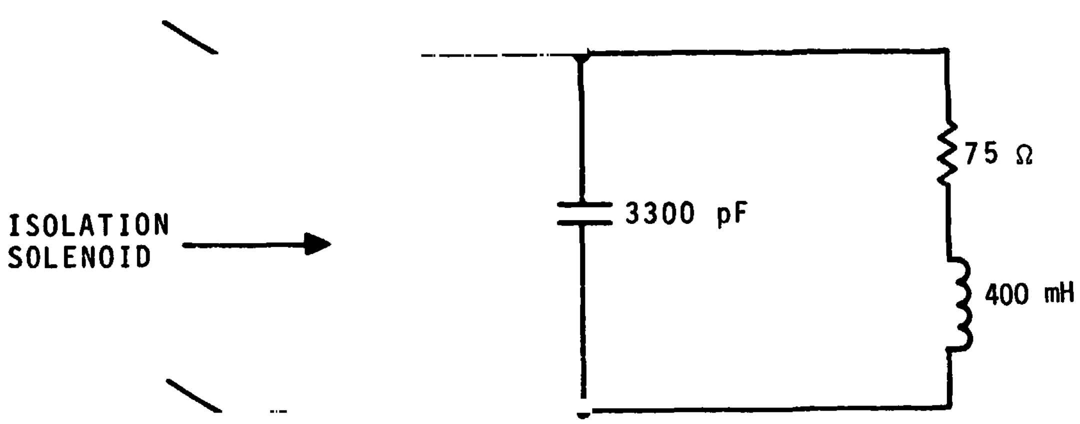


Figure 3-7. – Isolation valve.

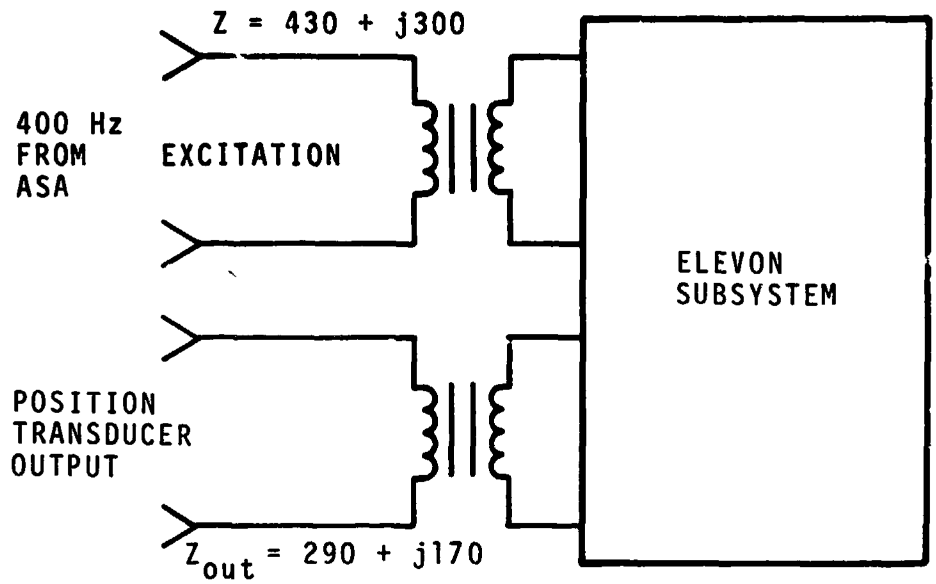


Figure 3-8. – Position transducer.

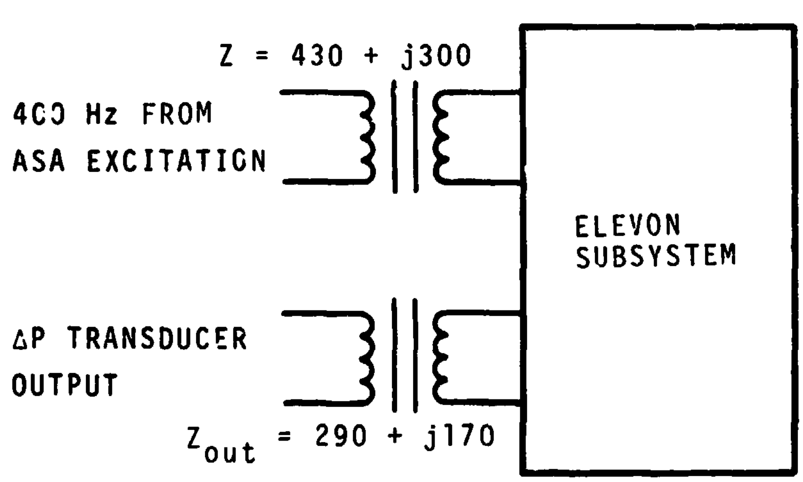


Figure 3-9. – ΔP transducer.

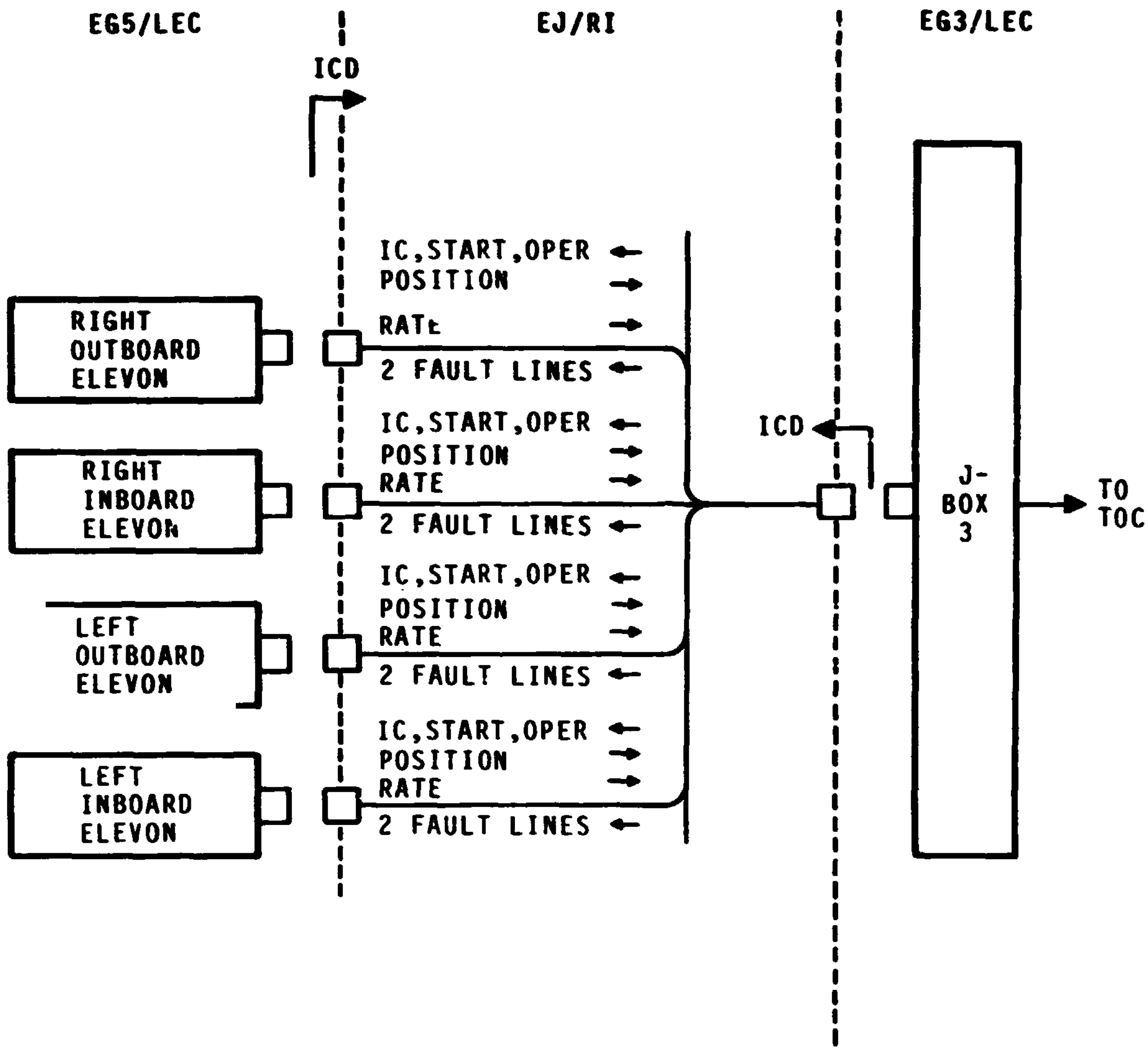


Figure 3-10. – SAS/J-box 3 interface.

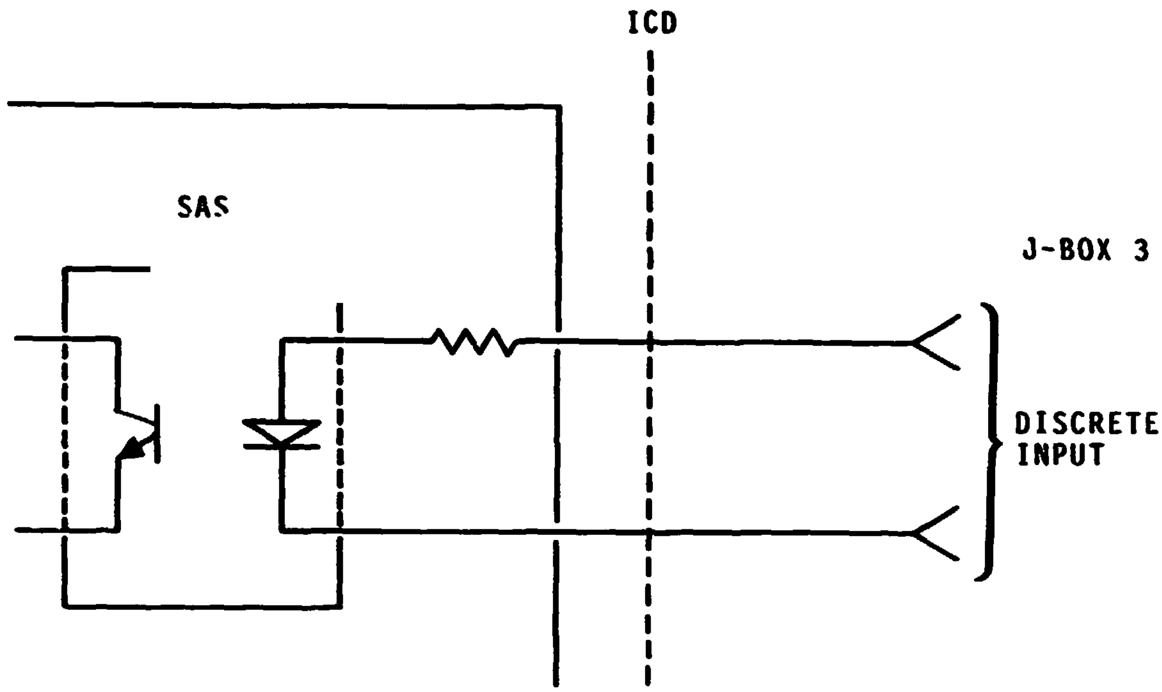


Figure 3-11. - Discrete input to SAS from J-box 3.

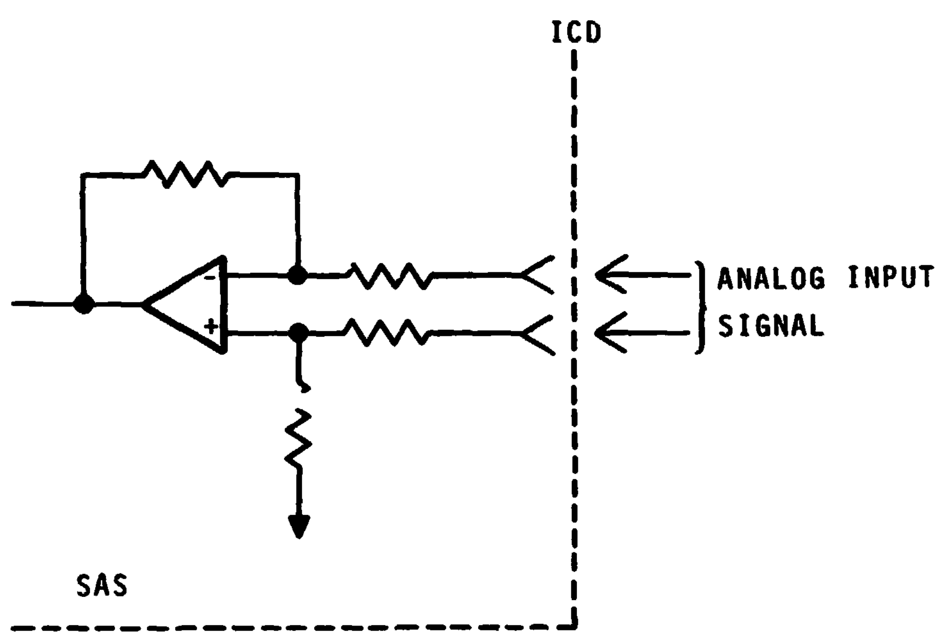


Figure 3-12. - Analog input to the SAS from J-box 3.

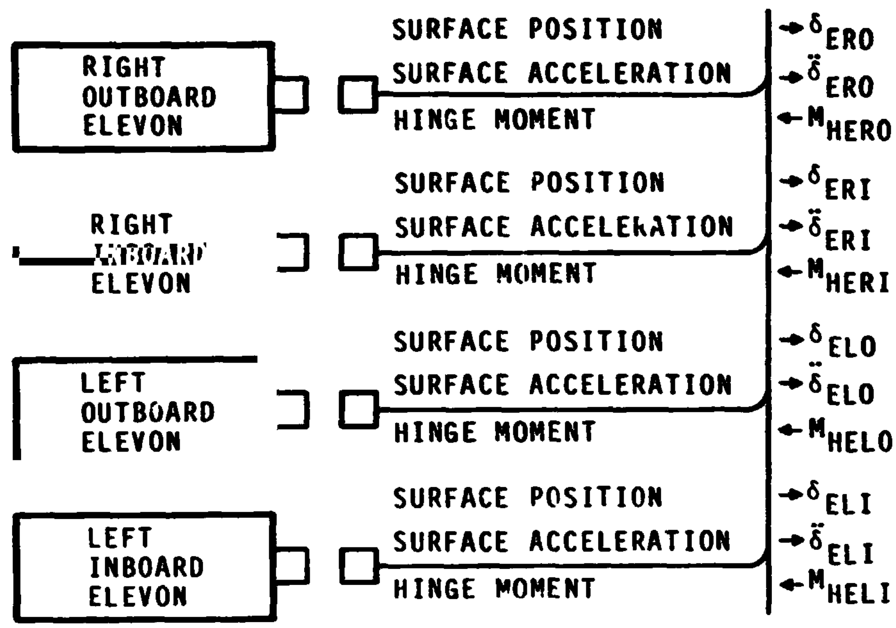


Figure 3-13. – SAS/SDS interface.

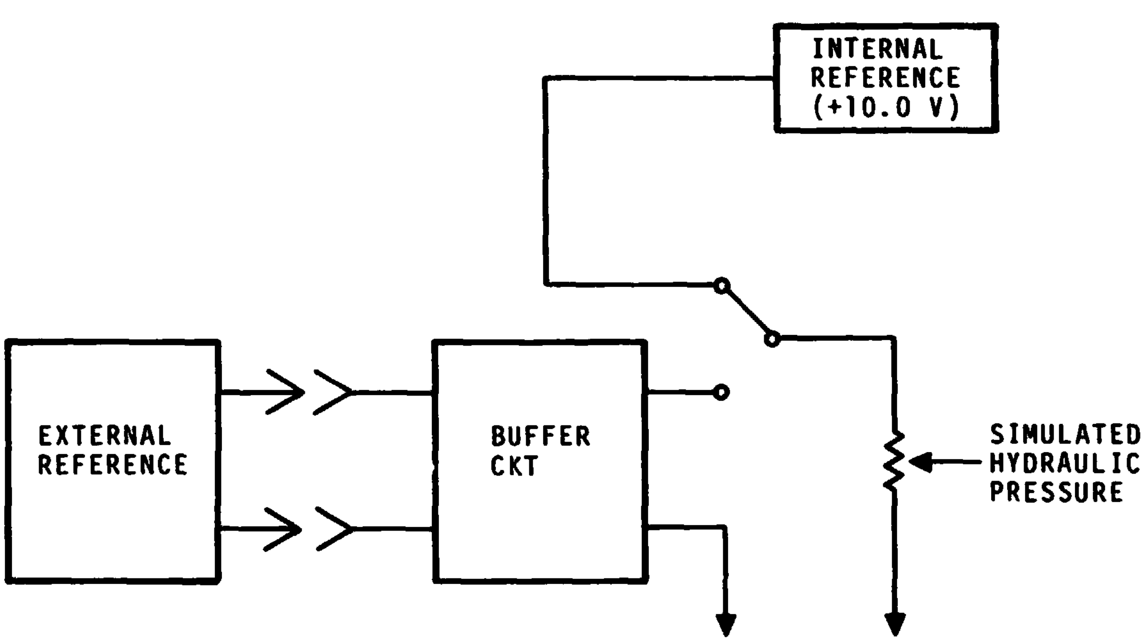


Figure 3-14. – System hydraulic pressure.

4. FAULT INSERTION

The capability to insert faults into the elevon is limited to those faults which will be detected by the redundancy management system. Faults which affect only elevon performance and are not detectable by the redundancy management system will not be implemented. Because faults are detected only via the elevon feedback to the ASA, any detectable fault will result in a significant change in some feedback parameters.

4.1 GENERAL

Fault insertion capability will be provided so that two faults may be remotely inserted in groups of two, with one fault labeled or designated as Fault Set 1 and the other as Fault Set 2. The elevon subsystem will contain manual switching circuitry to allow selecting:

- Faulted channel (see figure 4-1)
- Fault location
- Fault type
- Fault order

Fault capability will be as follows:

- ΔP Primary feedback (four channels)
- ΔP Secondary feedback (four channels)
- Position feedback (four channels)
- Isolation (ISO) valve (four channels)

The types of faults to be provided are ± hardover, zero, and open (ISO valve only).

To have a well defined identification of each fault, a maximum of two sets of faults will be located and classified at a given time. Faults will be distinguished as Fault 1 or Fault 2.

All fault request input data will be entered locally at the SAS by positioning switches on the fault insertion panel as depicted in figure 4-1.

Using one or both of two possible fault selection lines, TOC may initiate fault sets remotely as required. The order of the selected fault set level will be selected by TOC. It must be manually selected at the actuator subsystem.

Secondary faults will not be allowed. A secondary fault is defined as one which exists as a result of a previous fault.

4.2 CONTROL INTERFACE

4.2.1 SUBSYSTEM LINES

Two lines will be provided from the TOC for each elevon. One line will correspond to Fault Set 1 and the other to Fault Set 2.

4.2.2 LOGIC "Ø" STATE

A no-fault condition will be defined as a logic "Ø" state. The fault will be activated by setting the desired fault line to a logic "1" state. The ISO valve fault will require manual operation of the ISO valve switch at the selected elevon subsystem.

4.2.3 CLEARING FAULTS

Clearing of faults may be accomplished by:

- Setting the fault line back to logic "Ø" from TOC
- Setting the order switch to "no-fault" or resetting the master fault enable switch

- Resetting the ISO valve switch to normal (for the ISO valve fault only)

4.2.4 MASTER FAULT ENABLE SWITCH

A lockout switch to prevent inadvertent fault insertion will be provided. This will be implemented with a master fault enable switch on the subsystem in which the fault is to be inserted. This switch must be set to "enable" before any faults can be initiated. This switch will not affect operation of the ISO valve fault switch.

4.2.5 FAULT INSERTION LOGIC

Figure 4-2 shows schematically how faults will be inserted into the elevon subsystem. All faults except the ISO valve fault will be inserted into the appropriate circuits.

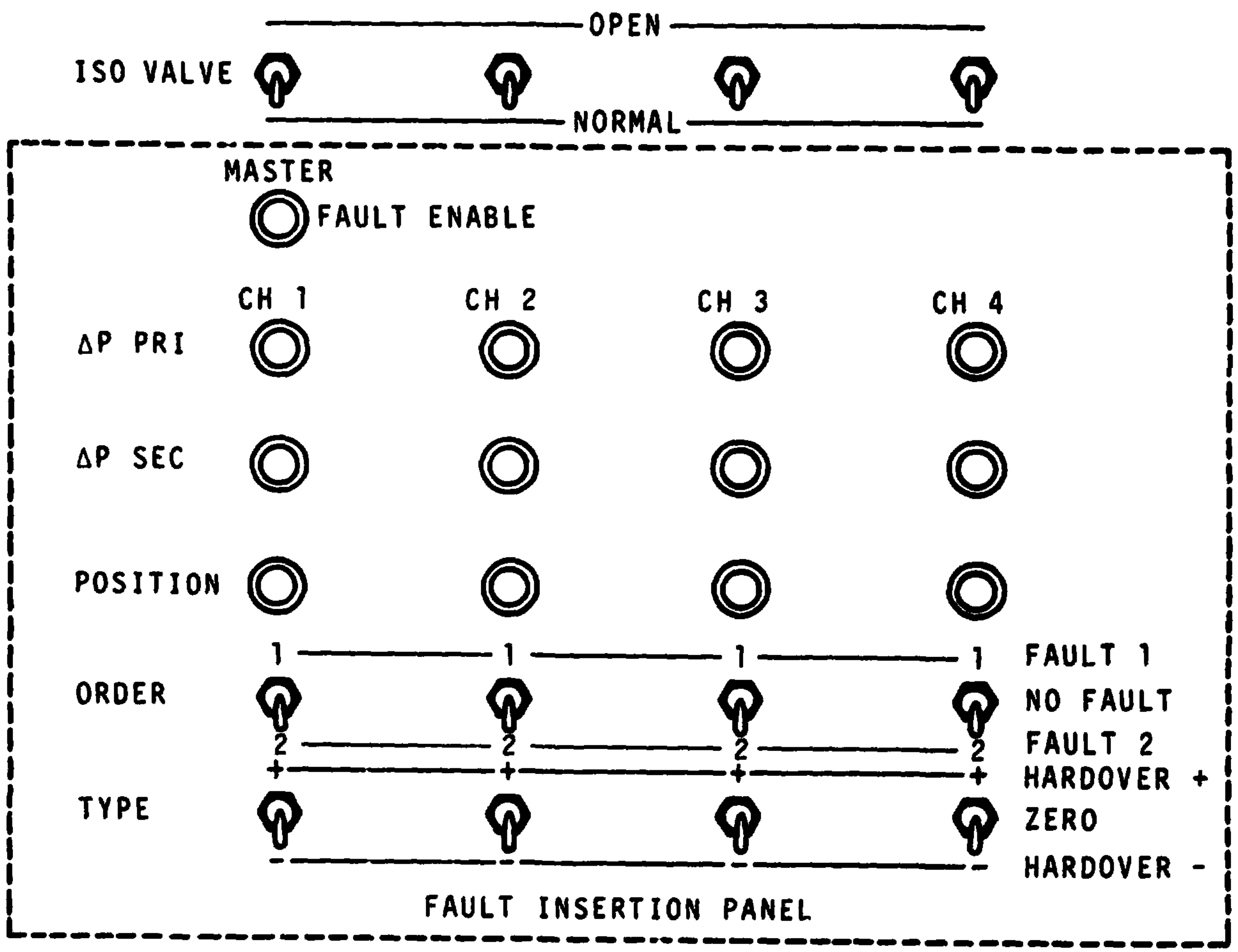


Figure 4-1. – Typical fault insertion panel.

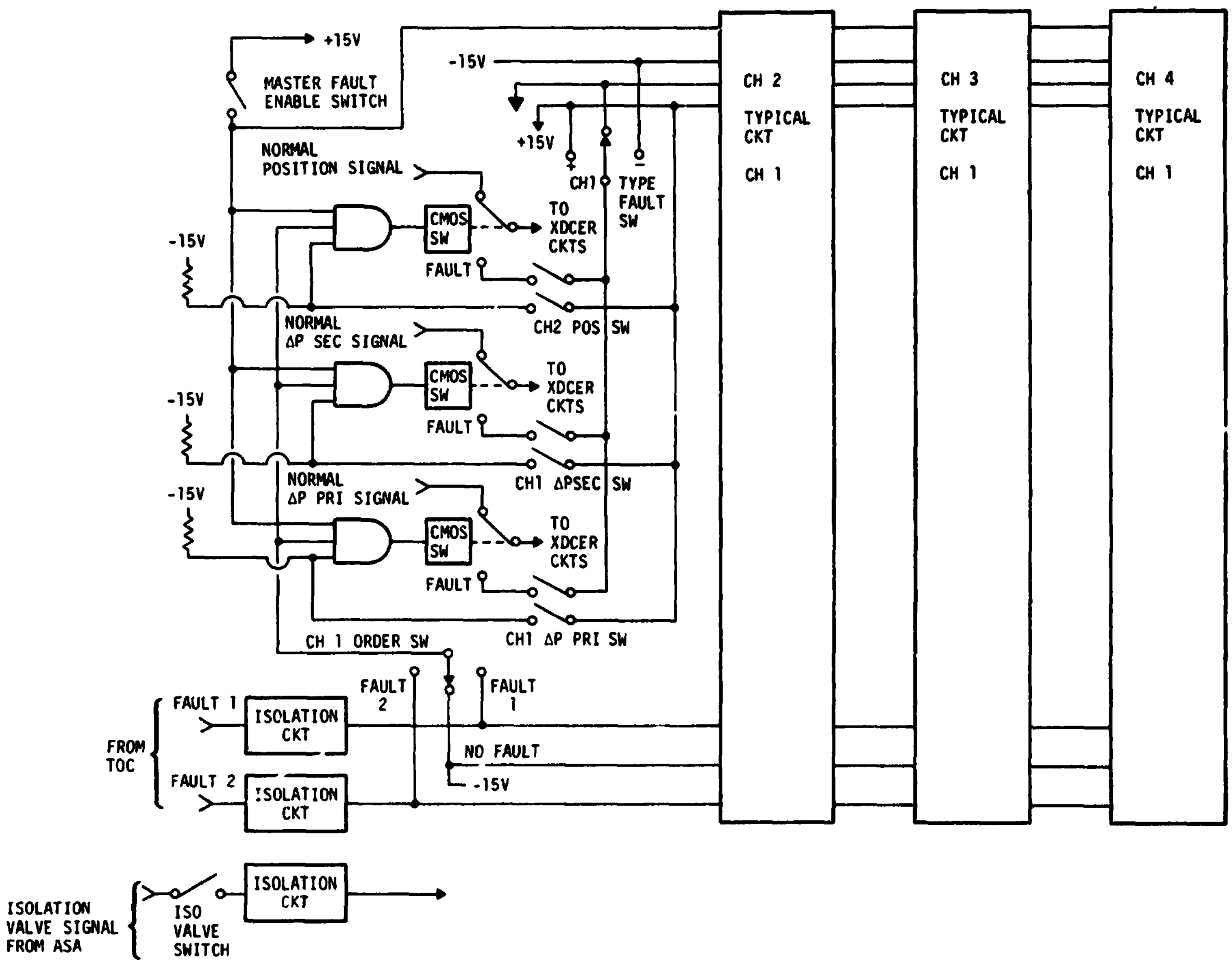


Figure 4-2. – Fault insertion logic.

5. MAINTENANCE

5.1 MAINTAINABILITY

The elevon will be partitioned on a function block basis to facilitate maintenance. Recommended spare boards and parts will be provided at the completion of the detailed design phase.

5.2 INTERCHANGEABILITY

a. Subsystems will not be interchangeable except for like units (inboard for inboard, outboard for outboard).

b. PC cards will be interchangeable on an identical function basis within a subsystem. Some cards will be interchangeable across subsystem lines (e.g., mod piston driver, buffer cards). See figure 5-1.

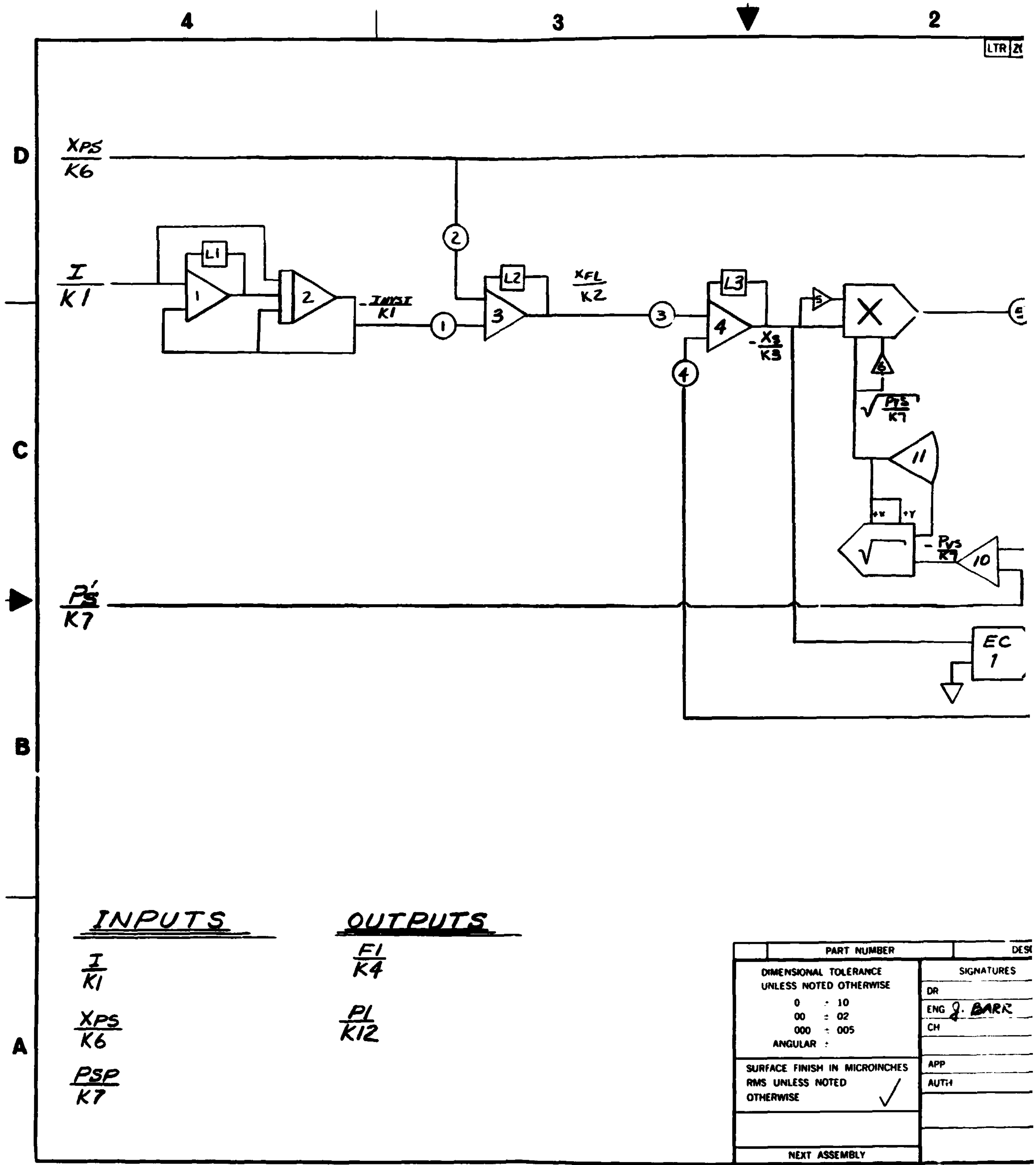


Figure 5-1. – Mod piston driver.

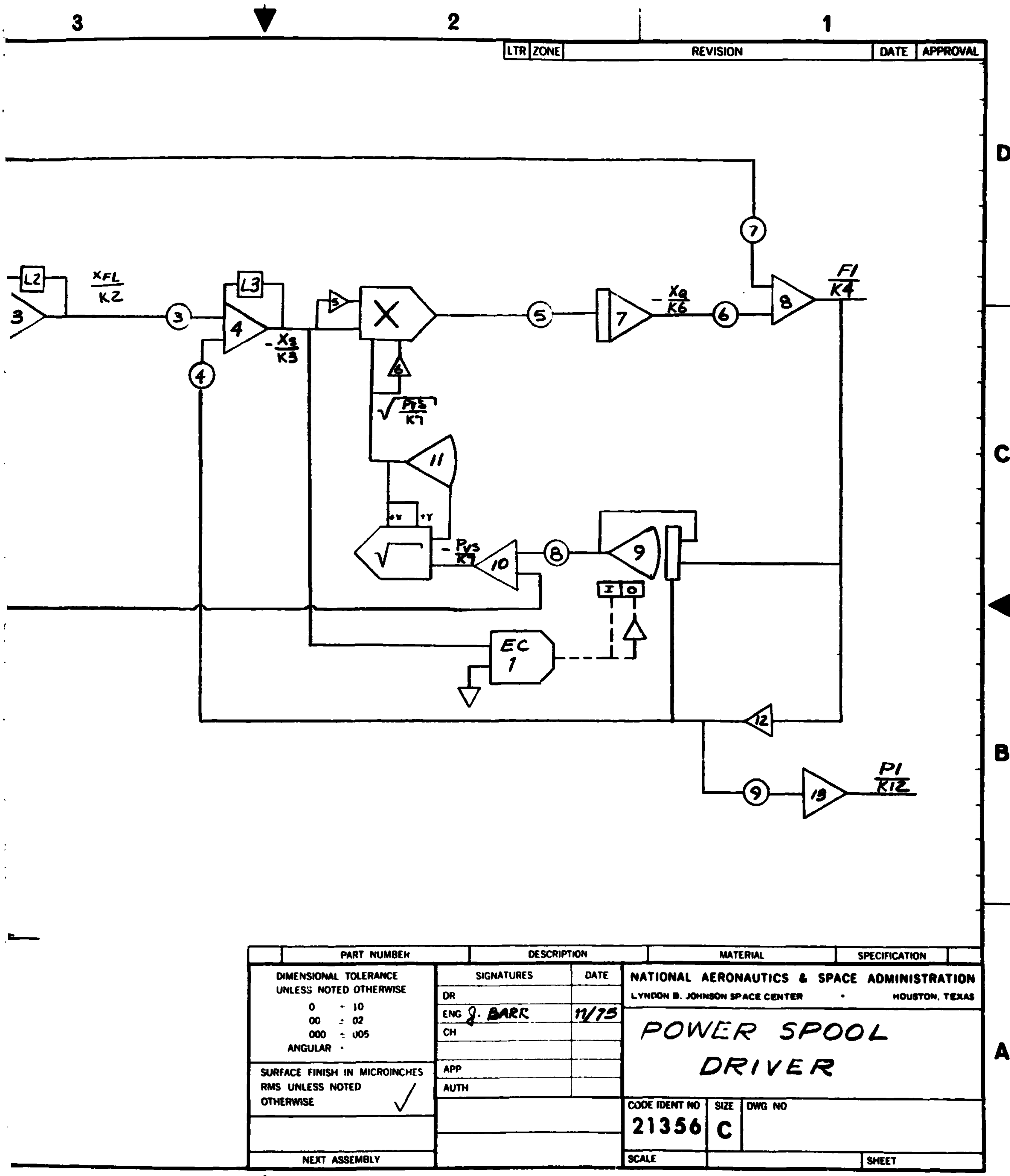


Figure 5-1. — Mod piston driver.

6. SUBSYSTEMS INITIALIZATION

The elevon subsystems will be initialized by either the Flight Systems software via the multiplexer-demultiplexer (MDM) or by the TOC. Initialization from the TOC will place an initial condition voltage on an integrator in each elevon actuator subsystem. The "operate" signal will be from the mode control via the TOC/J-box 3. The initial condition signal, IC, will be inserted into the integrator as shown in figure 6-1. See the discussion under section 3.3.2.

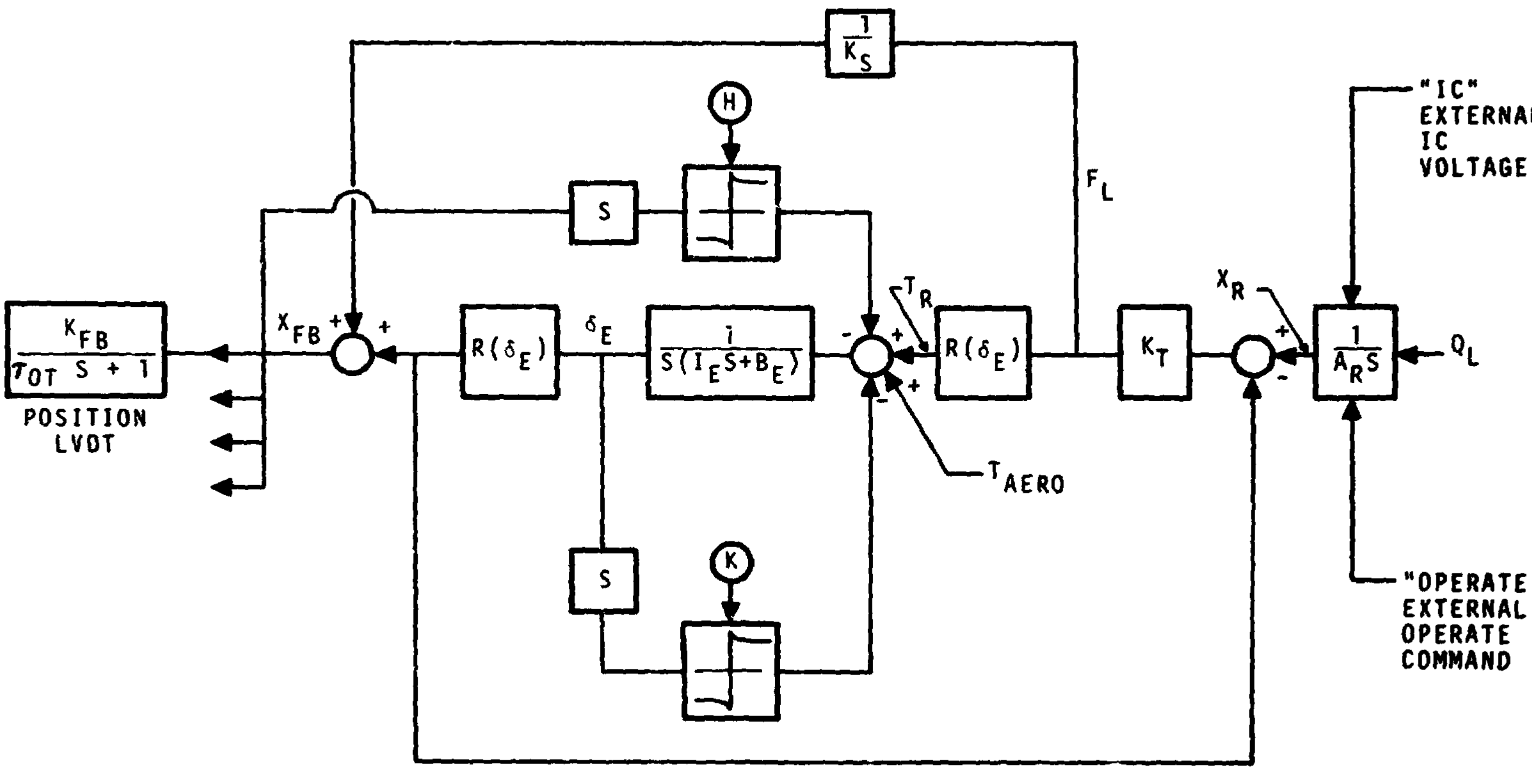


Figure 6-1. — Subsystem initialization.

7. DETAILED CIRCUIT DESIGN

The electronic circuitry shown in this section includes the interface circuits to the ASA, to TOC via J-box 3, and to SDS via the Shuttle Interface Subsystem (SIS). Also included are the schematics for the pressure/position transducer simulator actuator and part of the fault insertion circuitry.

7.1 GENERAL REQUIREMENTS

The interface circuitry will be designed to meet the signal requirements of the system/subsystem with which it is interfacing. These include transformer-coupled signals, buffered differential output signals, high-input impedance input amplifiers, and optical isolators. The signal levels and characteristics are discussed in section 3.

7.2 INTERFACE CIRCUITRY

7.2.1 HINGE MOMENT INTERFACE CIRCUIT

The hinge moment will be supplied to the SAS from SDS via SIS. The interface circuit is shown in figure 7-1. The signal will be a differential ±5 V. The differential signal will be received at the SIS/SAS interface with two unity-gain follower circuits, converted to ±5 V single ended, then amplified to ±10 V as required by the SAS.

7.2.2 INITIALIZATION INTERFACE CIRCUIT

The initialization signal will originate in the TOC as a 0.0 to 5.0 V full scale analog signal. The SAS circuitry requires ±10 V full scale, so the interface circuit will include the level translation as well as the isolation circuit. The circuit is shown in figure 7-2. The input will be received with two voltage follower circuits, then go to a differential input, single-ended output, unity-gain circuit. The signal will then be offset and amplified to ±10 V full scale single-ended.

7.2.3 RATE/POSITION INTERFACE

The rate/position interface to TOC will require level translation from ±10 V full scale to 0.0 to 5.0 V full scale. The circuit is shown in figure 7-3. The first amplifier will attenuate and translate the signal to the proper level. It will also invert the signal so a unity-gain inverter will be added to achieve the proper polarity.

7.2.4 TYPICAL TRANSFORMER ISOLATION INTERFACE

Transformer isolation will be used in the transducer interface circuits. The 400 Hz reference from the ASA will be transformer coupled into the SAS. Position feedback, ΔP_s, and ΔP_p will be transformer coupled out of SAS to the ASA. Figure 7-4 shows a simple block diagram of the circuit. Figure 7-5 (SAS1003S) shows the Pressure/Position Transducer Simulator Actuator schematic. The circuit will include a provision for fault insertion through a complementary metal oxide semiconductor (CMOS) switch U-4.

7.2.5 ELEVON SERVO VALVE INTERFACE

The elevon servo valve interface will receive the servo drive current from the ASA. The input signal will be a current loop of approximately ±8.6 mA. The voltage developed across the 470-ohm resistor will be applied to the input of a high-impedance amplifier (see fig. 7-6). The output will then feed the SAS. A schematic (SAS1004S) of the circuit board with four channels is shown in figure 7-7.

7.2.6 ELEVON ISOLATION VALVE INTERFACE

The elevon isolation valve interface circuit is shown in figure 7-8. The signal will originate in the ASA; it is referred to as a dc command signal in the Interface Control Document (ICD). It will be a nominal 28 V signal. It will be optically isolated from the SAS to maintain the grounding isolation as required by the SAIL program. See figure 7-9.

7.2.7 POSITION/ACCELERATION INTERFACE

The position and acceleration interface is shown in figure 7-10. The signal flow will be from SAS to SDS via the SIS. The SIS interface will require ±5 V full scale differential. The interface circuit will attenuate the ±10 V single-ended signal from SAS to the required differential level.

7.2.8 OPTICAL-ISOLATOR INTERFACE

The optical-isolator interface circuit is shown in figure 7-11 for the mode/fault insertion control signals. This type of circuit will be used throughout the SAS for interfacing input signals of a discrete nature. The mode control circuit is shown in figure 7-12. When TOC initiates the start discrete, the "Q" output of the flip-flop will go high, which in turn will close the switches for initialization (not shown). The circuits will remain in this initialization state until TOC sends an operate signal. At that time the flip-flop will be reset, the "Q" output will go low, and the initialization switches will be switched back to the operate mode.

7.2.9 FAULT INSERTION

The fault insertion is schematically shown in figure 7-13. The fault insertion control circuits are shown in figures 7-14 and 7-15. There will be two fault types, Fault 1 and Fault 2, initiated by TOC. Fault switching will be set up manually by toggle switches on the SAS front panels. Then the system will be ready to be initiated by Fault 1 or Fault 2. There will be separate switches for each of the four channels per elevon. This will allow all four channels to have either Fault 1 or Fault 2 initiation exclusive of which fault enables the other channels. Faults will be inserted into ΔP_p, ΔP_s, and position either individually or together as chosen by the manual switching. However, in a given channel, only hardover (+), hardover (-), or zero will be allowed in a given fault setup.

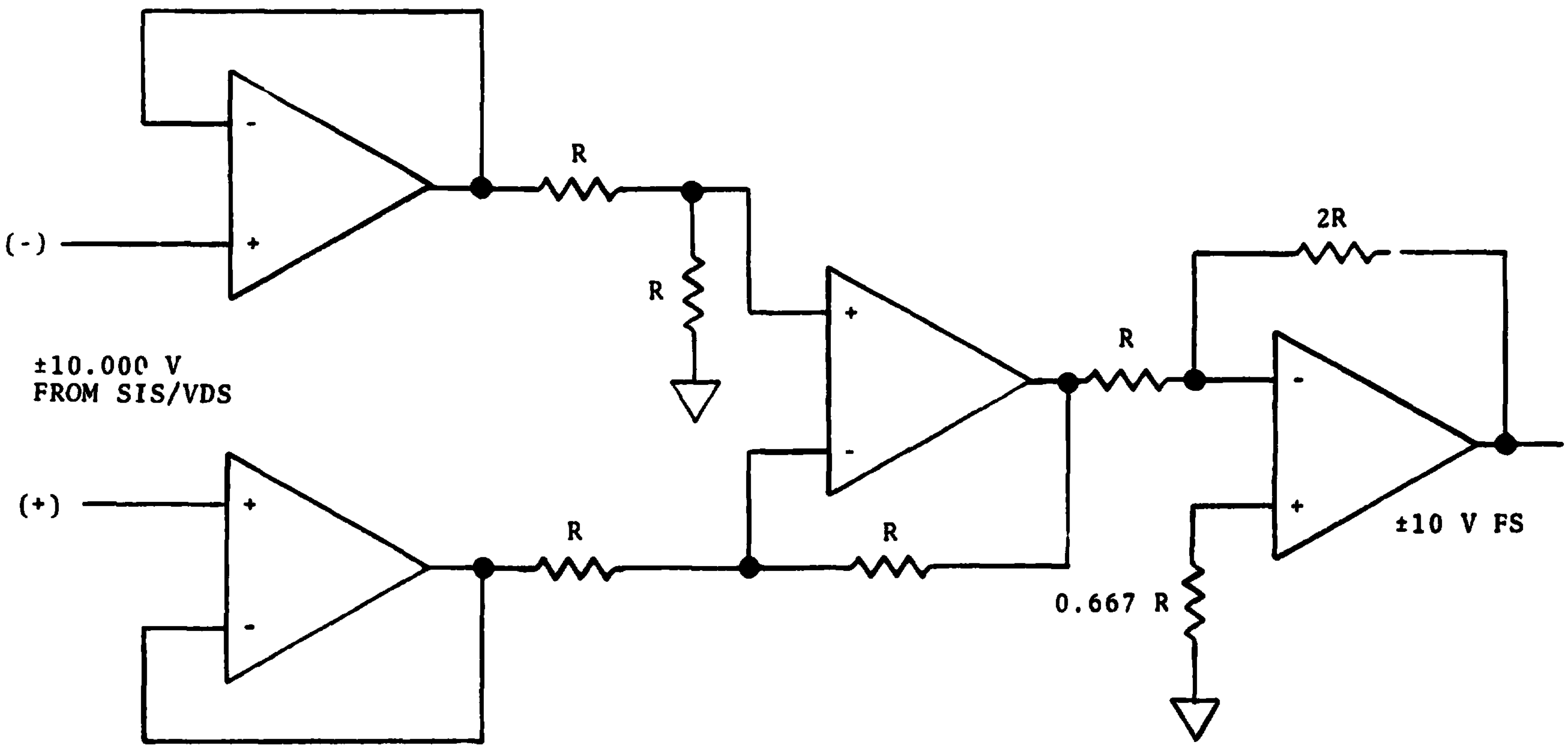


Figure 7-1. — Hinge moment SIS/SAS interface.

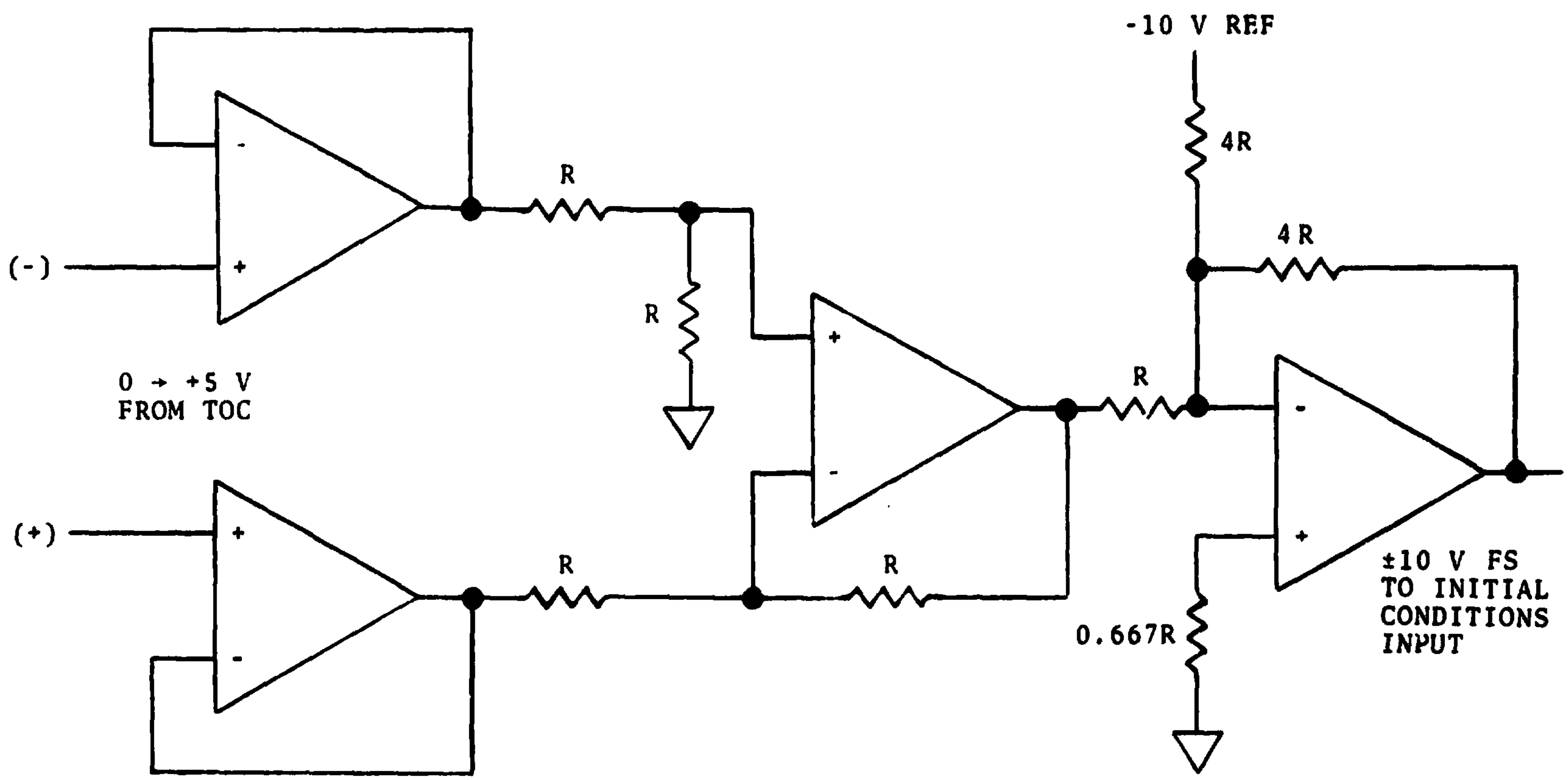


Figure 7-2. – Initialization TOC/ASA interface.

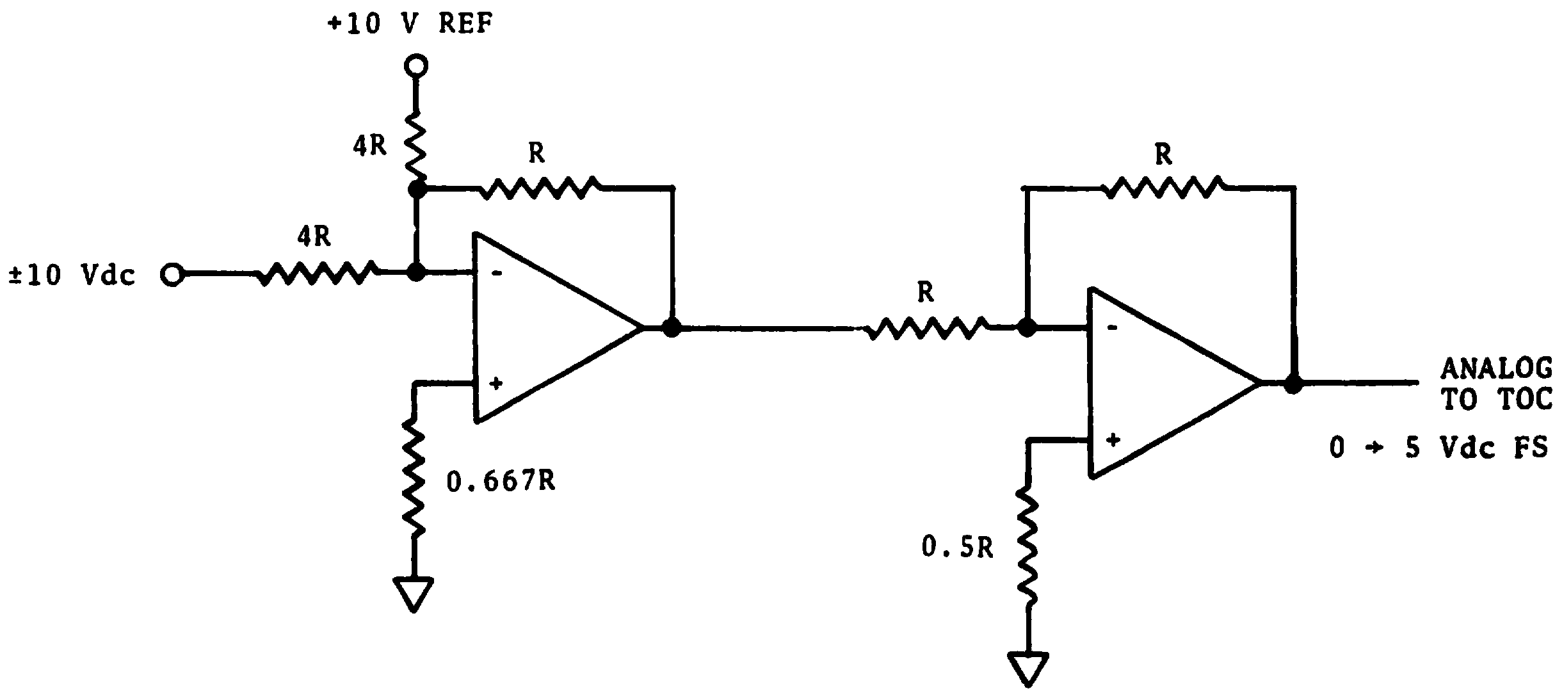


Figure 7-3. — Rate position SAS/TOC interface.

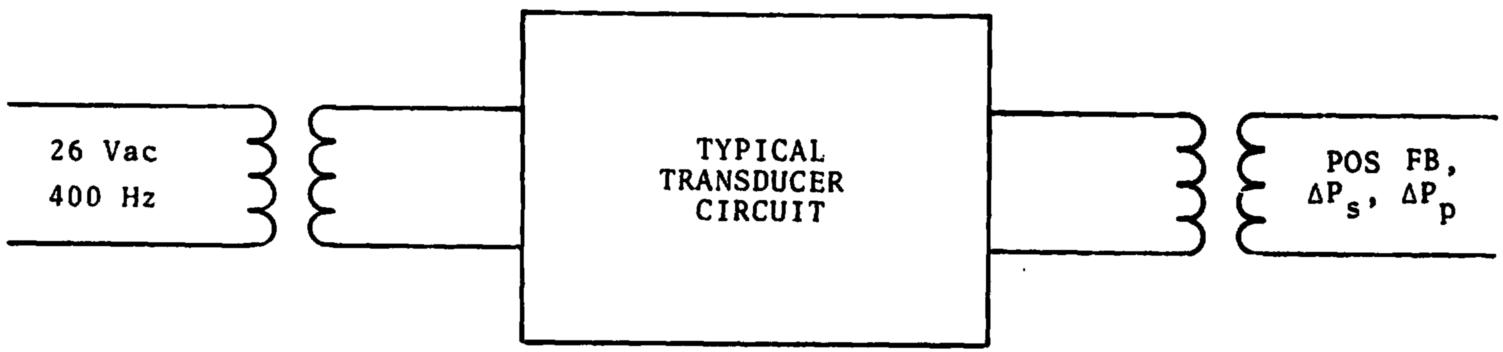


Figure 7-4. – Typical transformer – coupled isolation circuit ASA/SAS.

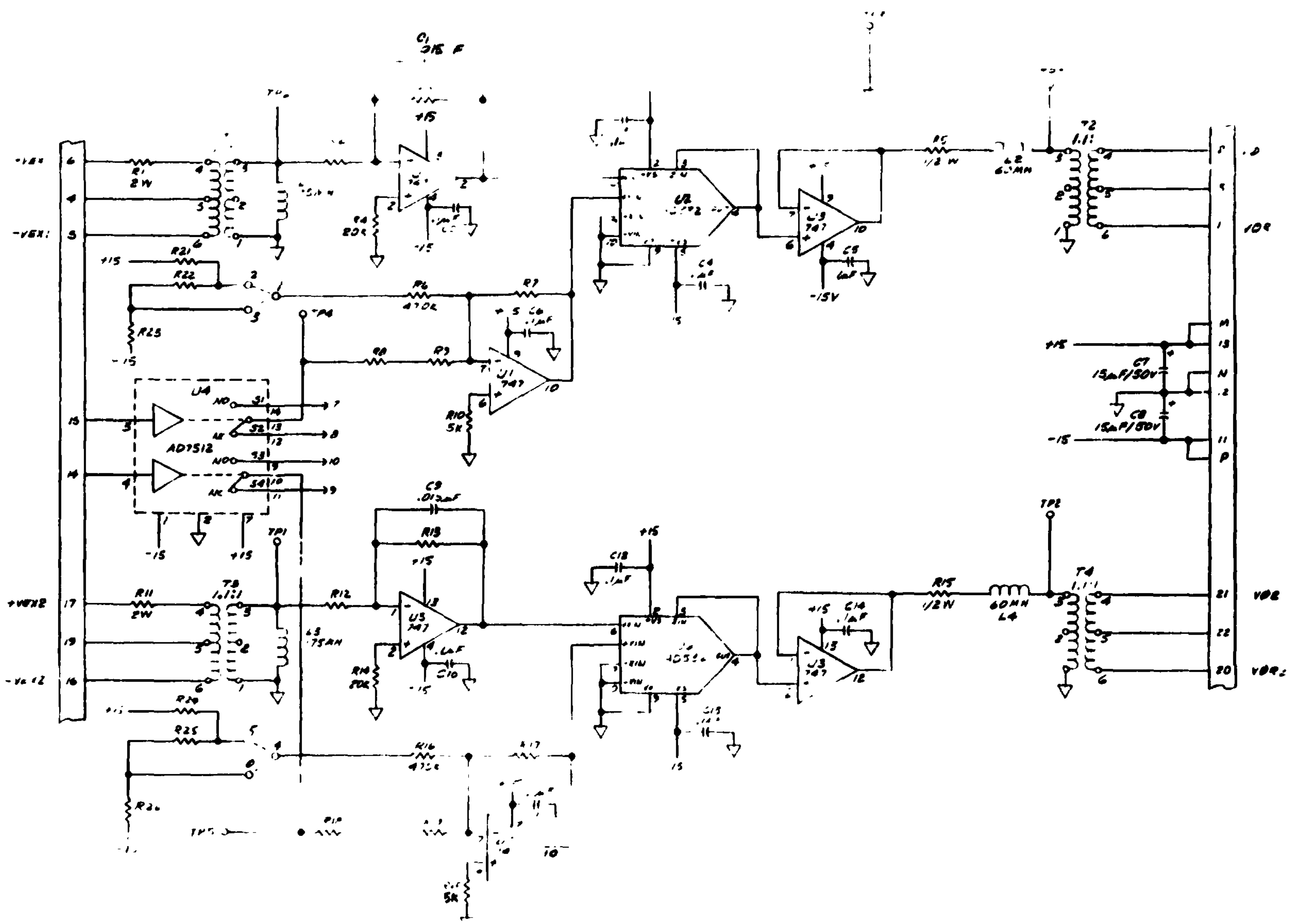


Figure 7-5. — Pressure/Position Transducer
Simulator Actuator Subsystem.

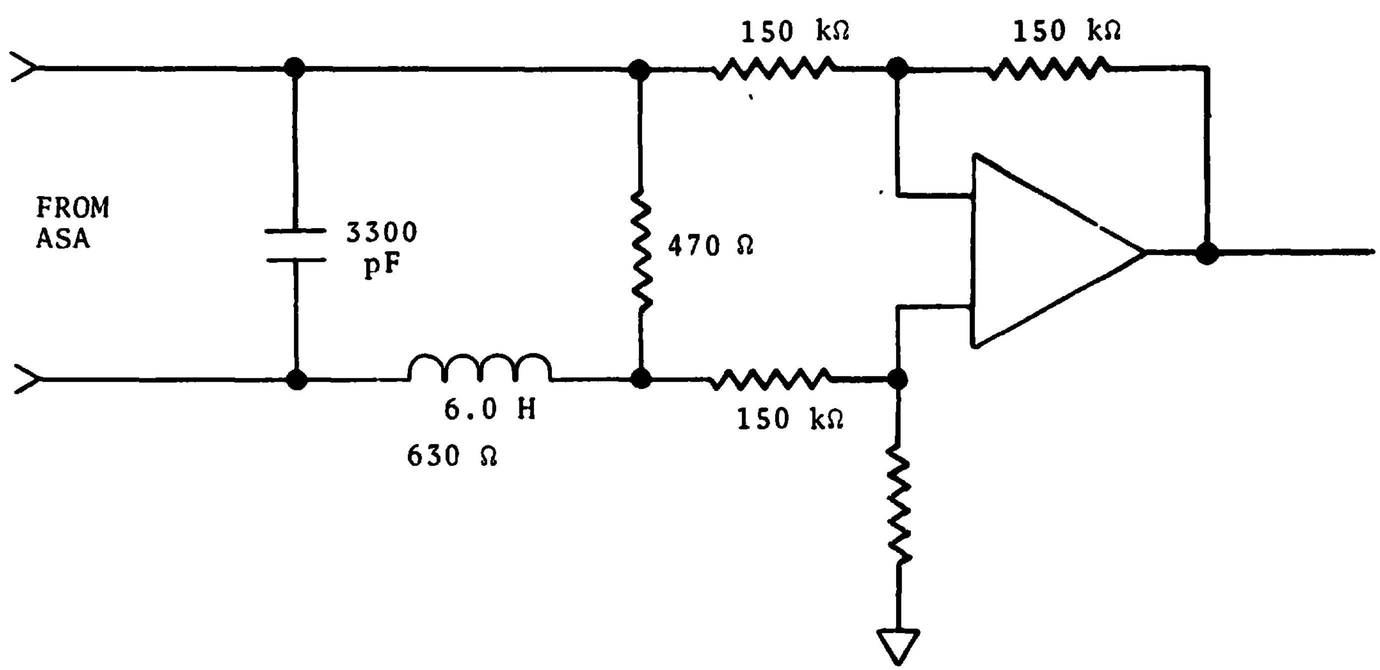


Figure 7-6. – Elevon servo value ASA/SAS interface

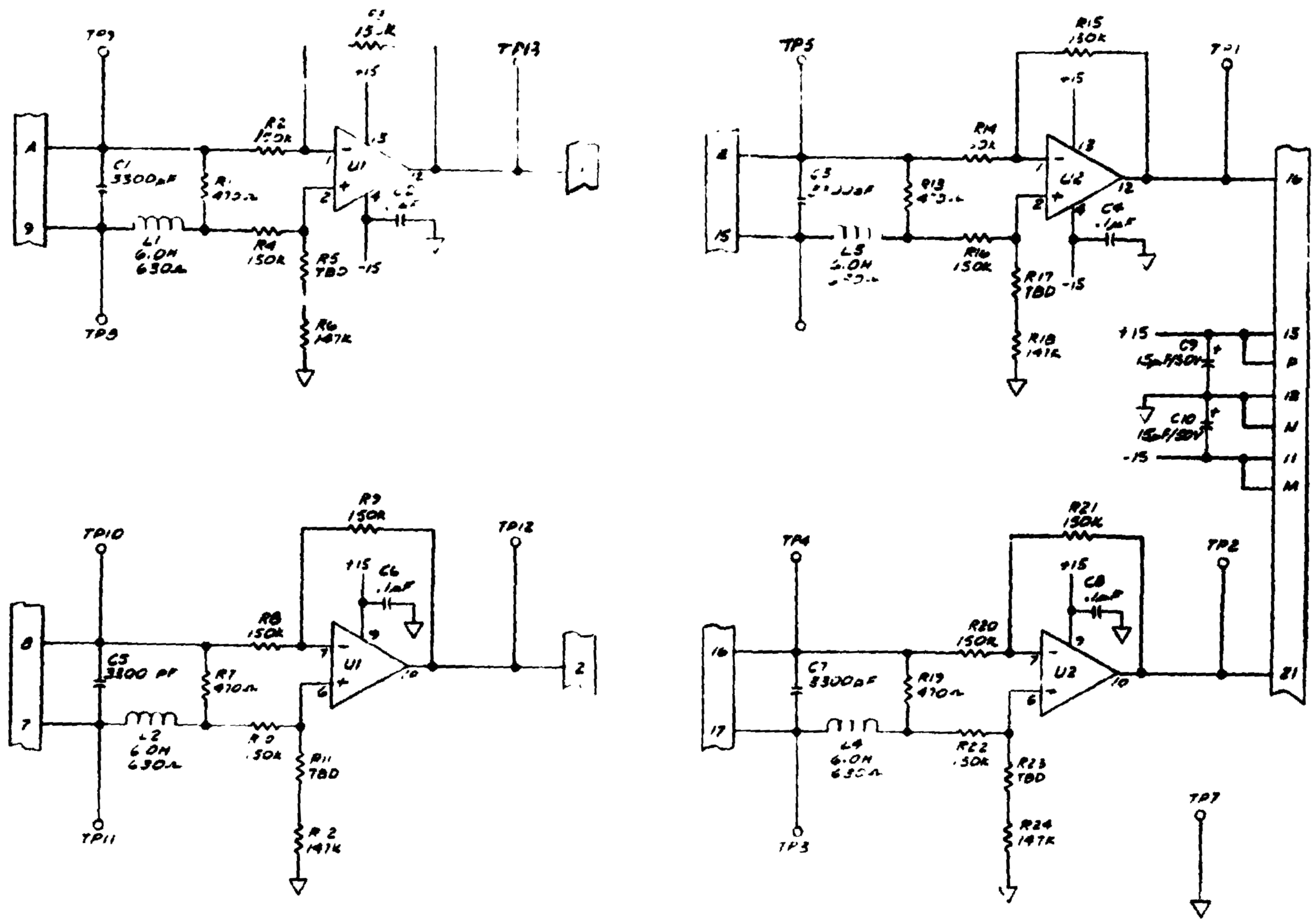


Figure 7-7. – Servo Valve Interface Simulator Actuator Subsystem.

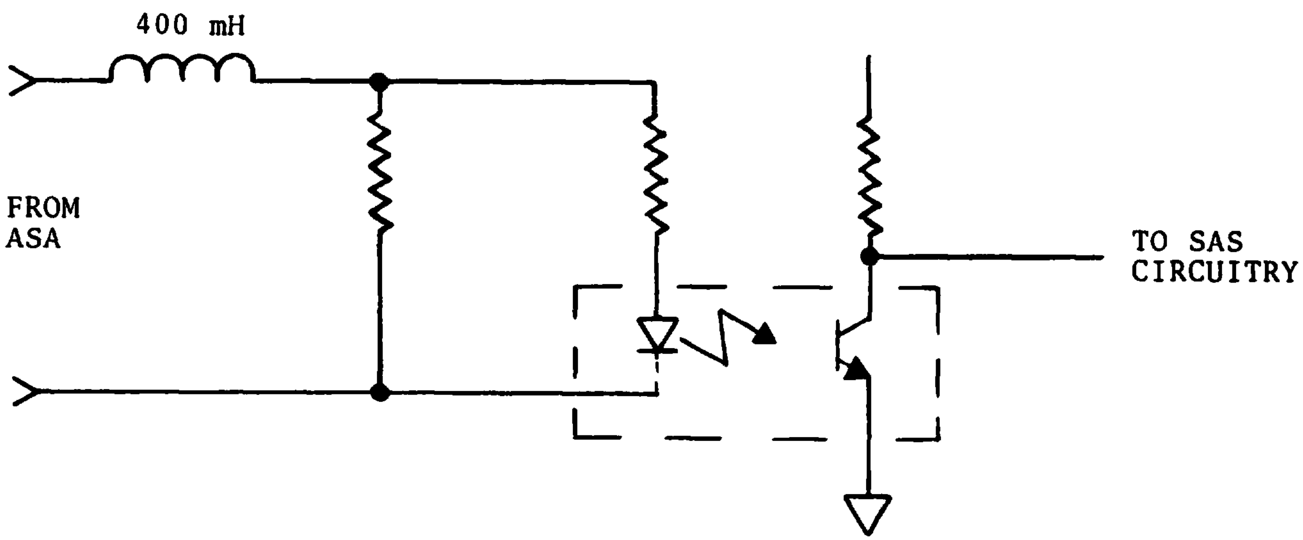


Figure 7-8. — Elevon isolation valve ASA/SAS interface

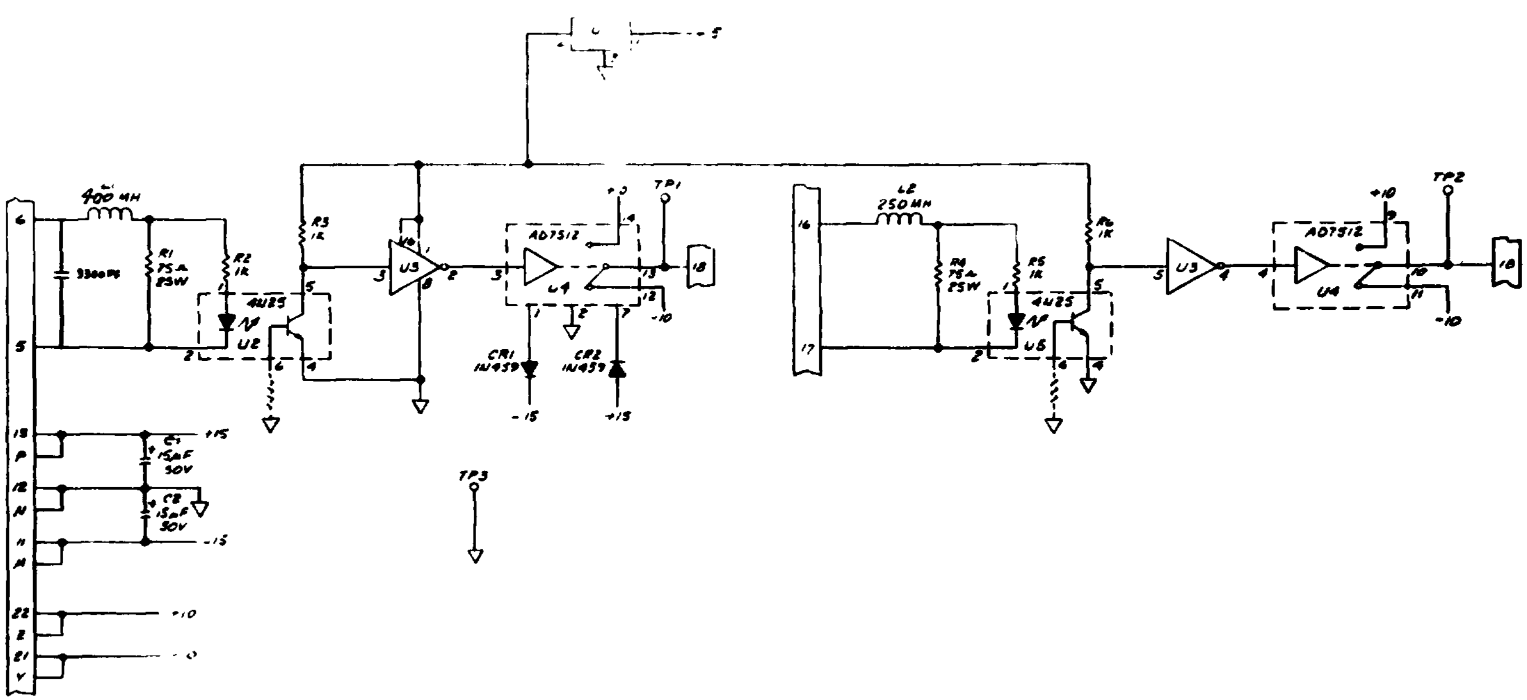


Figure 7-9. – ISO Valve Interface Simulator Actuator Subsystem.

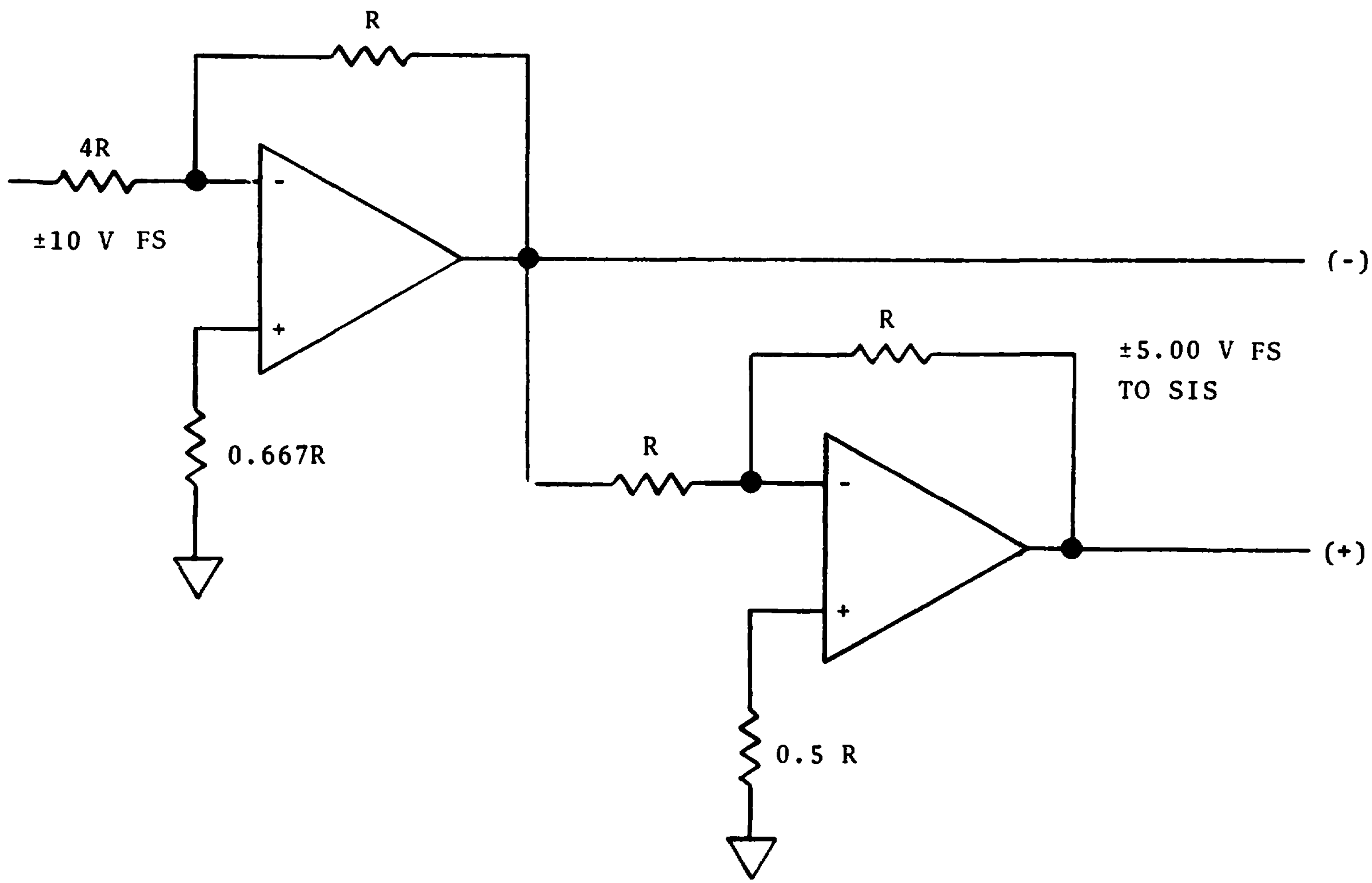


Figure 7-10. — Position acceleration SAS/SIS interface.

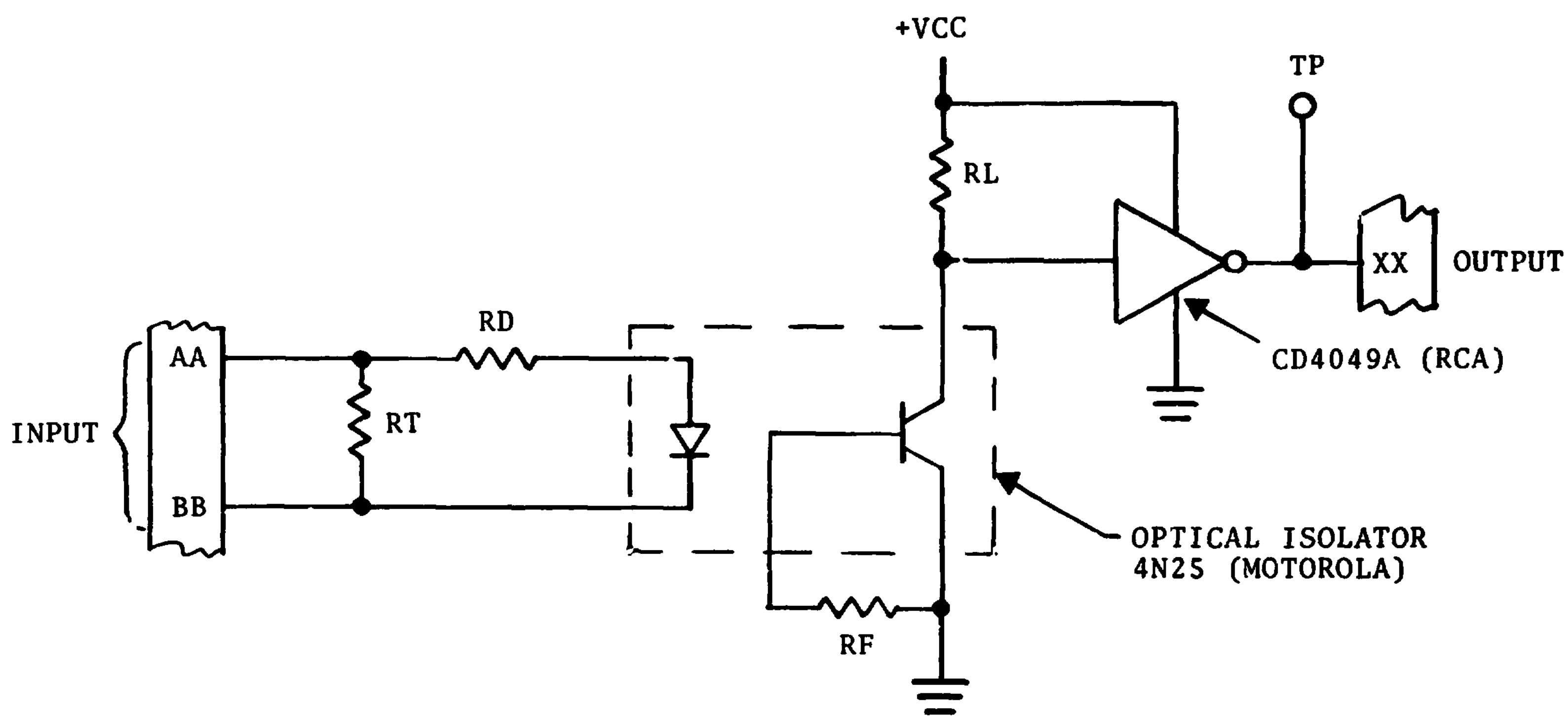


Figure 7-11. – Optical-isolator circuit (typical) mode/fault insertion.

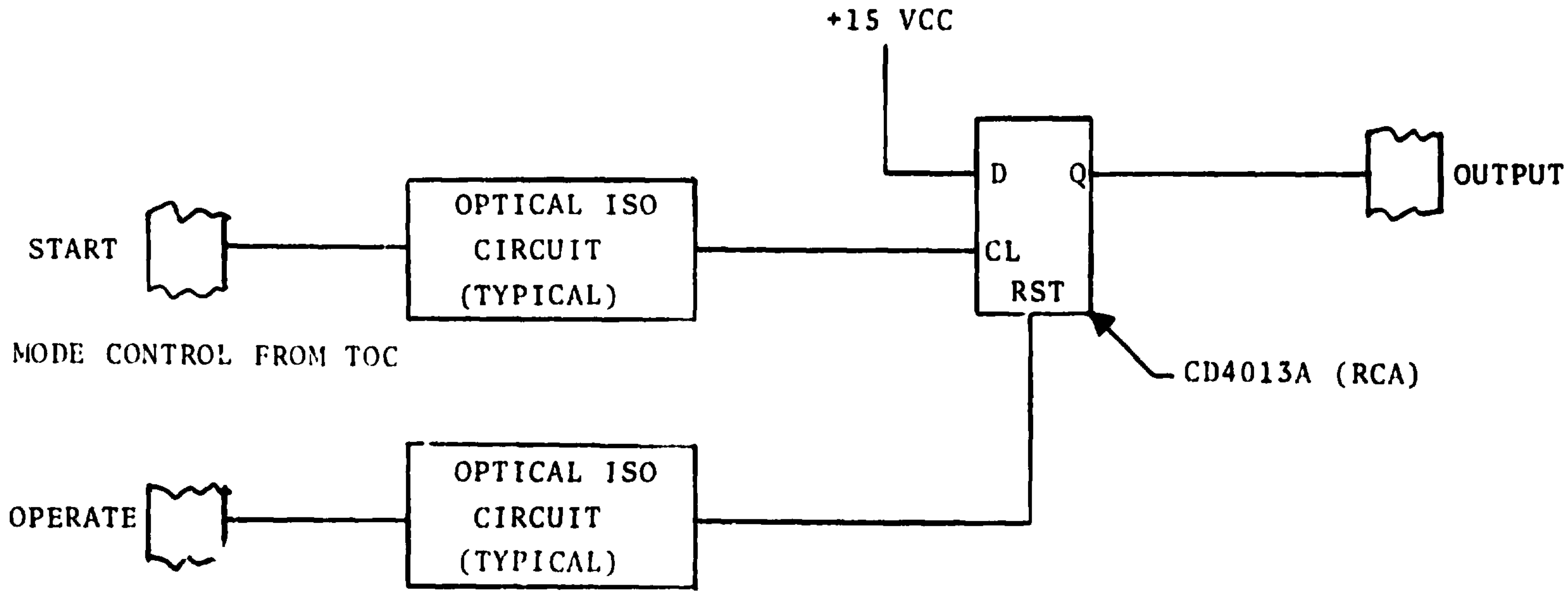


Figure 7-12. – Mode control circuit (typical).

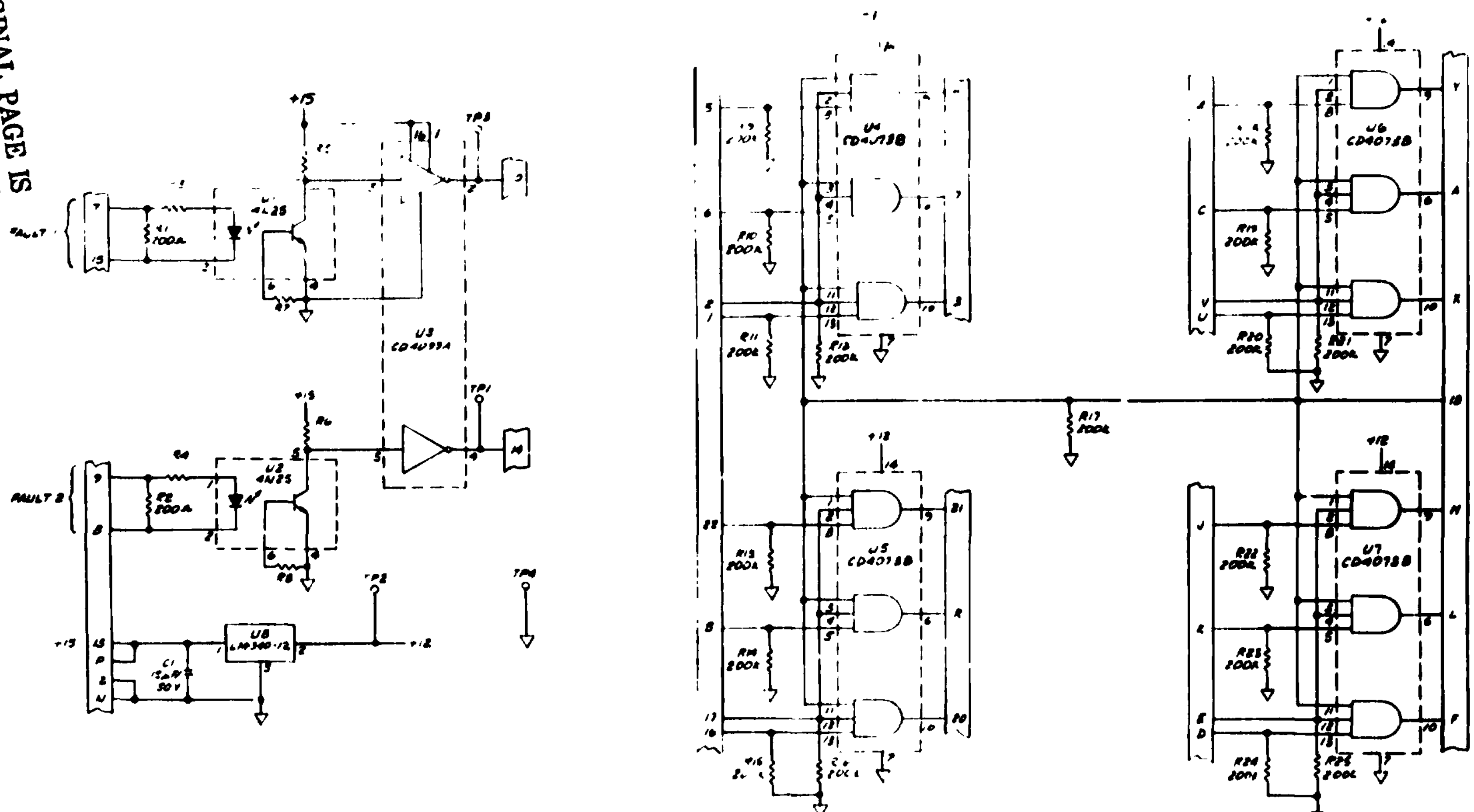


Figure 7-13. – Fault Insertion Simulator
Actuator Subsystem.

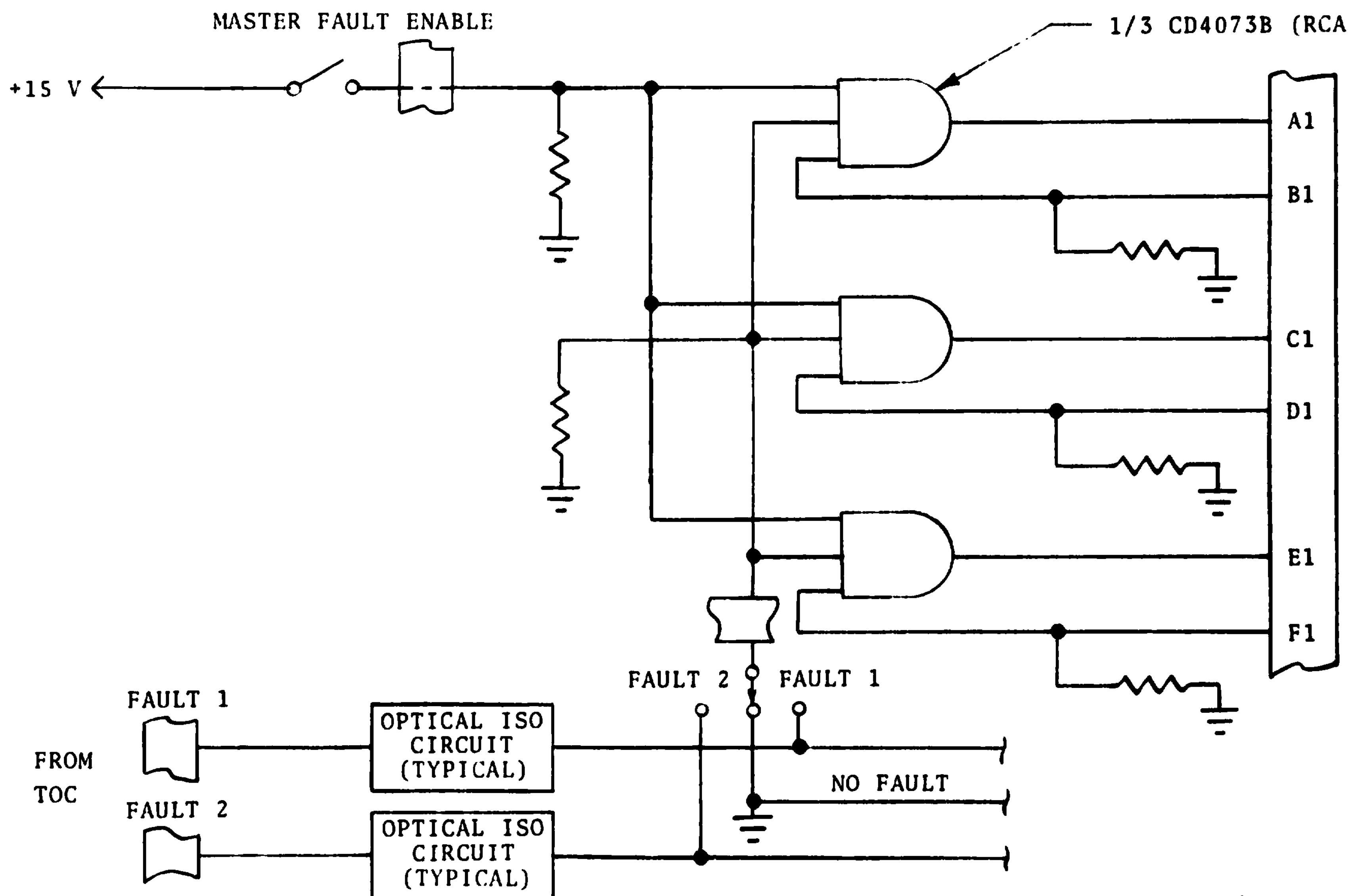


Figure 7-14. – SAS/TOC interface fault insertion switching circuit (typical) part A.

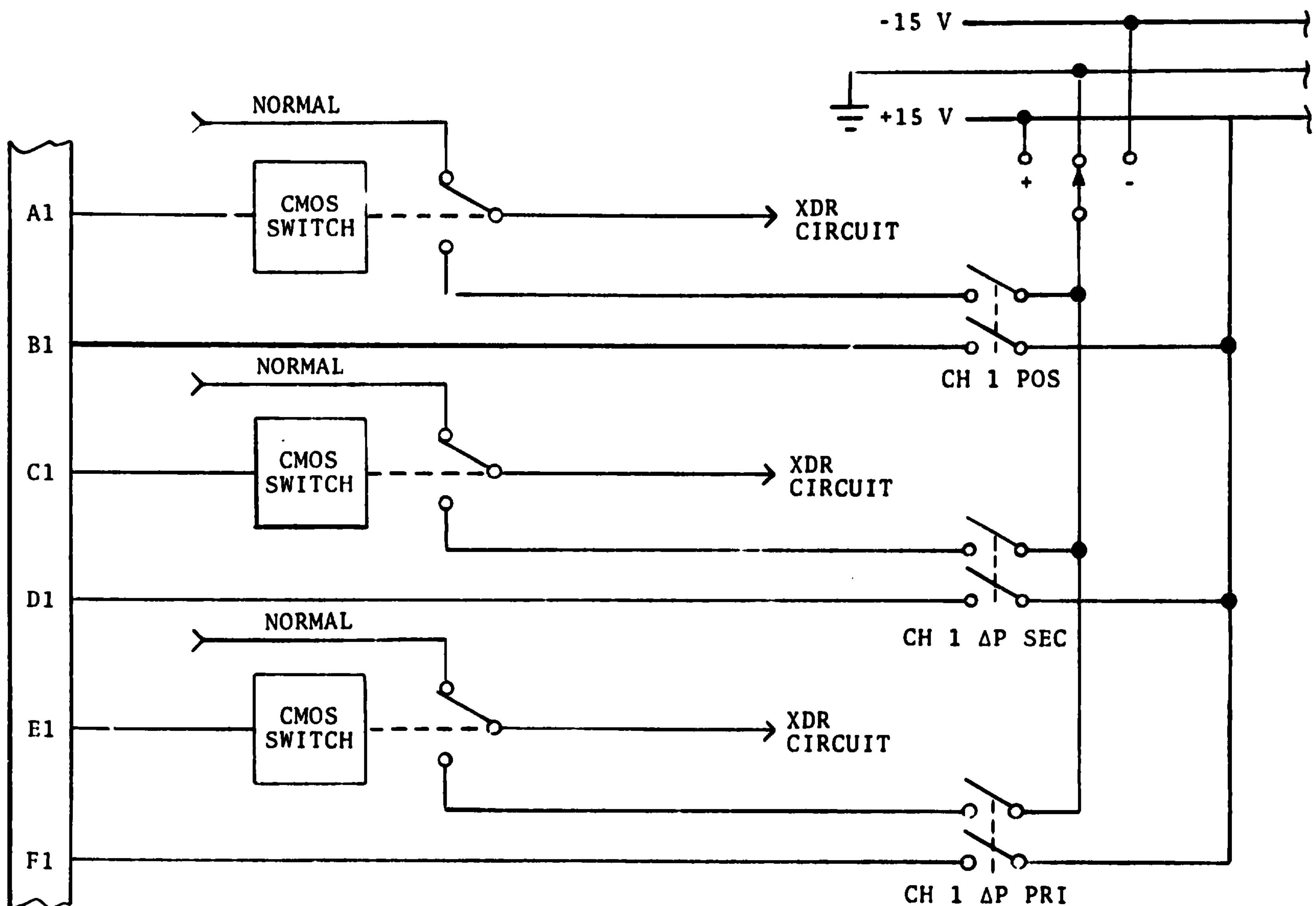


Figure 7-15. – SAS/TOC interface fault insertion switching circuit (typical) part B.

APPENDIX A

MODEL 1 LISTING

```
TITLE 625/34-5479  ELEVON ACTUATOR MODEL 1                     11.25.75
*        FULL-UP  MODEL  FREQUENCY  RESPONSE
*
*   SYSTEM MACROS
*
*  LIM1  IS A LIMITED FIRST ORDER SYSTEM
MACRO  Y=LIM1(YDOT,P1,P2)
PROCEDURE DYDT=LIMA(Y,YDOT,P1,P2)
       DYDT=YDOT
       IF(Y.LE.P1) DYDT=AMAX1(0.,YDOT)
       IF(Y.GE.P2) DYDT=AMIN1(0.,YDOT)
ENDPROCEDURE
      Y = INTGRL(0.0,DYDT)
ENDMAC

*  LIM2  IS A LIMITED SECOND ORDER SYSTEM
MACRO  Z,ZDOT=LIM2(ZDDOT,P3,P4)
PROCEDURE ZDDOT1,ZDOT1=LIMB(Z,ZDOT,ZDDOT,P3,P4)
       IF(Z.LE.P3) GO TO 30
       IF(Z.GE.P4) GO TO 31
       ZDDOT1=ZDDOT
       ZDOT1=ZDOT
       GO TO 32
    30 ZDDOT1=AMAX1(0.,ZDDOT)
       ZDOT1=AMAX1(0.,ZDOT)
       GO TO 32
    31 ZDDOT1=AMIN1(0.,ZDDOT)
       ZDOT1=AMIN1(0.,ZDOT)
    32 CONTINUE
ENDPROCEDURE
       ZDOT=INTGRL(0.,ZDDOT1)
      Z  =INTGRL(0.,ZDOT1)
ENDMAC

*
INITIAL
*
```

```
*****************************************************************************
*        FULL-UP 'HCKE'  ELEVCN  MODEL
```

```
*        FULL-UP 'HCKE'  ELEVCN  MODEL
```

```
*****************************************************************************

*****  CONSTANTS AND FUNCTICNS ARE FOR THE OUTBOARD ACTUATOR SYSTEM  ***
CONST    AC=8.975E-3,      AP=2.761E-2,     APS=1.930E-1,    AW=1.602E1
CONST    BE=1.500E4,       BETA=1.717E5,    BP=6.480E-2,     BPS=1.386
CONST    CI=1.852E2,       CL=1.030E-8
CONST    COUL=11.60,       CP=3.430E-5,     CQ=4.590,        CTM=8.760E-5
CONST    CTW=1.096E-1,     DELK=1.550E4
CONST    DELEIN=1.000
CONST    IC=0.0,           IE=2.063E3,      IL=8.500
CONST    KAMP=15.00
CONST    KASA=0.352712,    KH=3.190E-1,     KC=1.710,        KFB=1.173
CONST    KL=1.00,          KN=1.380E-4
CONST    KP=1.200E3,       KPG=5.030E-3,    KPT=1.670E-3
CONST    KQPS=5.180E1,     KS=1.540E5,      KT=1.286E5,      KTM=4.500E-2
CONST    KXPS=6.220,       K0=4.24,         K1=1.548E-1,     K2=5.224E-2
CONST    K12=1.494E-1,     K22=4.460E-2
CONST    L=1.000E-3,       LAP=1.100E-3,    LD=7.070E-1,     LW=1.593E-2
CONST    MP=6.830E-5,      MPS=2.070E-3,    PSS=3.000E3
CONST    P3=0.0,         P4=(15.0,20.0,25.0),         P5=0.0
CONST    RAD=57.2958,      RCL=4.750E-5
CONST    RLE=1.452E3,      TAUC=1.000E-1,  THERC= 0.0,       TW1=4.000E-3
CONST    V=8.380E-2,       VT=6.20E-1,      WD=3.14E2,       XFL=1.000E-3
CONST    X0=1.850E-3,      XPSL=5.500E-2

   FUNCTICN  MOMENT  =  (-36.5,7.767), (-35.0,7.884), ...
         (-30.0,8.223), (-25.0,8.481), (-20.0,8.661), ...
         (-15.0,8.766), (-10.0,8.820), (-7.705,8.793),...
         (-5.00,8.767), ( 0.00,8.671), ( 5.00,8.517), ...
         ( 10.0,8.307), ( 15.0,8.047), ( 20.0,7.740), ( 21.5,7.639)

   FUNCTICN  STROKE  =  (-36.5,-4.266),(-35.0,-4.061),...
         (-30.0,-3.358),(-25.0,-2.628),(-20.0,-1.880),...
         (-15.0,-1.110),(-10.0,-0.352),(-7.705,0.000),...
         (-5.00, 0.415),( 0.00, 1.176),( 5.00, 1.927),...
```

```
          ( 10.0, 2.661),( 15.0, 3.375),( 20.0, 4.064),( 21.5, 4.266)

DYNAMIC

NOSORT
      PNA= LIMIT(-3000.,3000.,PNA)
      IF(XSALIM.GE.0.015)  DXSALM= AMIN1(0.0,CASALM)
      IF(XSALIM.LE.-0.015) DXSALM= AMAX1(0.0,CASALM)
      XSALIM= LIMIT(-0.015,0.015,XSALIM)
      XPS= LIMIT(-XPSL,XPSL,XPS)
      XR= LIMIT(-5.442,3.090,XR)
      DELE= LIMIT(-0.637045,0.375245,DELE)
SORT
*
*    ASA SIGNAL OUTPUT
*
*    THE ASA OUTPUT IS RATE LIMITED TO 20 DEGREES/SECOND
      CMDELE= DELEIN*SINE(P3,P4,P5)
      DELINC= AFGEN(STROKE,CMDELE)
      VCA    = (DELINC-1.176)*KFB
      IA = (VCA-VZ)*KAMP - VK
      ILIMA=LIMIT(-IL,IL,IA)
*
*    ELEVON TORQUER MOTOR
*
      H =  0.020 + (0.16/7.6)*ABS(ILIMA)
      TCHSA=HSTRSS(0.,-H,H,ILIMA)
      TCA=KTM*TCHSA
*
*     FLAPPER VALVE DYNAMICS
*

      ETA=TCA-(PNA*KN)-(KXPS*XPSLIM)
      XFA=ETA*LN
      XFLIMA=LIMIT(-XFL,XFL,XFA)
      QNA=XFLIMA*2.*CT
      QXA=2.*(AP-AC)*DXSALM
      QZA=QNA-QXA
```

```
      DPNA=((-PNA*(CTL+CTW*XO))+G2A)/(V/(2.0*BETA))
       PNA=LIMI(DPNA,-3000.,3000.)
      FCHA=PNA*(AP-AC)
*
*    SECONDARY VALVE DYNAMICS
*
      FCHTA=POA*AC
      XSAISW= DEADSP(-0.20,0.20,FCHA-FCHTA)
      XSAFSW= FCNSW(DXSALM,-0.2,XSAISW,0.2)
      FORCEA=FCHA-FCHTA-XSAFSW
      DDXSA= (FORCEA-BP*DXSALM-KP*XSALIM)/MP
        XSALIM,DXSALM= LIM2(DDXSA,-0.015,0.015)
*
*    SECONDARY FLOW EQUATIONS
*
      PSP= PSS-(K12+ABS(QL)*K22)*ABS(GL)
       PVS= PSP - PCA*SIGN(1.,XSALIM)
      QQA= CQ*XSALIM*SIGN(SQRT(ABS(PVS)),PVS)
      QXSALM=DXSALM*AC
      QSA= QQA + QXSALM
      DXQA=QSA/APS
      XQA=INTGRL(IC,DXQA)
      XQSA=XQA-XPSLIM
      FA=XQSA*4.*BETA*APS*APS/VT
      PCA=FA/APS
*
*    MOD PISTON DYNAMICS
*
      XPSDSP= DEADSP(-L,L,XPSLIM)
      AGL= ABS(GL)
      PSL= PSS-(K0+(K1+K2*AGL)*AGL)
      FBH= (PSL-PPRE)*XPSDSP*KH
      COULF1= DEADSP(-COUL,COUL,(4.0*FA)-FBH)
      COULF= FCNSW(DXPSL,-COUL,COULF1,COUL)
```

```
      FTCT=(4.*FA)-FRc-COLLF
      DDXPS=(FTCT-(APc*DXPS))/MPS
      DXPSL=DERIV(IC,XPSLIM)
       XPS,DXPS=LIM2(DDXPS,-XPSL,XPSL)
      XPSLIM=LIMIT(-XPSL,XPSL,XPS)
*
*     LOAD FLOW EQUATIONS
*

      XPSEFF= SQRT((L-ABS(XPSLIM))**2+RCL**2)
      XPSPL= AMAX1(0.1E-3,L+XPSLIM)
      XPSML= AMAX1(0.1E-3,L-XPSLIM)
       PPRE=PL*SIGN(1.,XPSLIM)
      QL= IMPL(0.0,0.01,FCQL)
      PLKG= K0+(K1+K2*ABS(QL))*ABS(QL)
      PS=PSS-PLKQ
      PV=PS-PPRE
      APV= ABS(PV)
      APSMPL= ABS(PS-PL)
      APSPPL= ABS(PS+PL)
      TERM1= CL*APSMPL/XPSML
      TERM2= KQPS*RCL*SQRT(APSMPL)
      TERM3= CL*APSPPL/XPSPL
      TERM4= KQPS*RCL*SQRT(APSPPL)
      QLL= SIGN(AMIN1(TERM1,TERM2),PS-PL)-SIGN(AMIN1(TERM3,TERM4),PS+PL)
      QLH= KQPS*XPSEFF*SIGN(SQRT(APV),XPSLIM*F/) ...
           -SIGN(CL,XPSLIM)*(PS+PL*SIGN(1.0,XPSLIM))/(L+ABS(XPSLIM))
      DFCQL= ABS(XPSLIM)-LAP
      FCQL =  FCNSW(DFCQL, QLL, QLH, QLH)
*
*     RAM PISTON DYNAMICS
*
      DXR= QL/AR
      XR =  LIMI(DXR,-5.442,3.090)
      XTOT= XR-XSTR
      FLOOT= KT*XTOT
      PL=FLOOT/AR
      MR=AFGEN(MOMENT,DELED)
      TR=MR*FLOOT
```

```
      DELEK=DELE*KL
*  THE FOLLOWING PROCEDURE COMPUTES THE TOTAL TORQUE INCLUDING
*   THE EFFECTS OF ACTUATOR STICTION AND ELEVON STICTION.
      RLE1= RLE*MR
PROCEDURE      TTOT= STICTN(DDELED,DXFBK,DELK,RLE1,TR,TAERO,DELEK)
      TLIMIT=  DELK+RLE1
      T1= TR+TAERO-DELEK
      T2= FCNSW(DXFBK, RLE1,0.0,RLE1)
      T3=  FCNSW(DDELED,-DELK,0.0,DELK)
         IF(DXFBK .NE. 0.0)  GO TO 200
             IF(DDELED .NE. 0.0)  GO TO 120
*            TO HERE IF DXFBK.EQ.0  AND  DDELED.EQ.0
             TTOT= DEADSP(-TLIMIT,TLIMIT,T1)
             GO  TO  400
*            TO HERE IF DXFBK.EQ.0  AND  DDELED.NE.0
 120         TTOT= DEADSP(-RLE1,RLE1,T1-T3)
             GO TO 400
 200     CONTINUE
             IF(DDELED .NE. 0.0)  GO TO 300
*            TO HERE IF DXFBK.NE.0  AND  DDELED.EQ.0
             TTOT= DEADSP(-DELK,DELK,T1-T2)
             GO  TO  400
*            TO HERE IF DXFBK.NE.0  AND  DDELED.NE.0
 300         TTOT= T1-T2-T3
 400  CONTINUE
ENDPROCEDURE

      DDDELE=(TTOT-(BF*DDELE))/IE
       DELE,DDELE= LIM2(DDDELE,-0.637045, 0.375245)
      DELED=DELE*RAD
      DDELED =  DDELE*RAD
      STR  =  AFGEN(STROKE,DELED)
      XSTR =  STR - 1.1760
      XKS=FLOOT/KS
      XFBK= XSTR + XKS
      DXFBK=DERIV(0.0,XFBK)
*
*    DELTA-PL TRANSDUCER AND  ASA DEMODULATOR
```

```
*
      PLHYST= HSTRSS(0.0,-62.5,62.5,PL)
      VLDOT= PLHYST*KET
      VL =  REALPL(IC,TCT,VLDOT)
      VWDDOT= WD*WD*VL
      VW=  CMPXPL(IC,IC,LD,WD,VWDDOT)
      VK1= LEDLAG(TAUC*KC,TAUC,VW)
      VK2=REALPL(IC,TAUC,VW)
      VK =  VK1 - VK2
*
*    POSITION TRANSDUCER AND  ASA DEMODULATOR
*
      LVDTD= KFB*XFBK
      LVDT=  REALPL(IC,TDT,LVDTD)
      VZDDOT= WD*WD*LVDT
      VZ =  CMPXPL(IC,IC,LD,WD,VZDDOT)
*
*    DELTA-PS TRANSDUCER AND ASA DEMODULATOR
*
      VPSDOT= PCA*KPT*WD*WD
      VPS =  CMPXPL(IC,IC,LD,WD,VPSDOT)

TERMINAL
METHOD RKSFX
TIMER    DELT=0.00005,OUTDEL=0.005,PRDEL=0.010,FINTIM=2.000
RANGE    VCA,IA,ILIMA,TCHSA,TCA,ETA,QNA,GXA,GZA,PNA,...
         FOPA,FORTA,XSAFSW,FORCEA,XSALIM,DXSALM,...
         FSP,PVS,QOA,DXSALM,QSA,XGA,FA,FCA,FBF,COULF,FTOT,APS,IAPS,...
         XPSLIM,PS,PV,QL,XR,XTOT,FL,TR,ITCT,...
         DDELED,DELED,XSTR,XKS,XFBK,LVDT,VZ,PLHYST,VL,VW,VK
LABEL 625/34-5479  ELEVON ACTUATOR   MODEL 1                 11.25.75
LABEL                SMALL  SIGNAL  FREQUENCY  RESPONSE
OUTPUT   DELED,CMDELE
OUTPUT     ILIMA,DXFBK
LABEL    ELEVON  POSITION   DEGREES
OUTPUT   DDELED
LABEL    ELEVON  RATE   DEGREES/SECOND
OUTPUT   ILIMA
LABEL    TORQUER  MOTOR  CURRENT   MILLIAMPS
```

```
OUTPUT    XPSLIM
LABEL     POWER  SPOOL  POSITION    INCHES
OUTPUT    QL
LABEL     LOAD  FLOW    CUBIC INCHES / SECOND
OUTPUT    PL
LABEL     LOAD  PRESSURE    LBS/SQUARE INCH
OUTPUT    PSL
LABEL     DROPPED  SUPPLY  PRESSURE    LBS/SQUARE INCH
OUTPUT    PDA
LABEL     SECONDARY  DELTA  PRESSURE  FEEDBACK    LBS/SQUARE INCH
OUTPUT    STR,XFBK
LABEL     ACTUATOR  POSITION   INCHES
LABEL     ACTUATOR  POSITION  FEEDBACK    INCHES
OUTPUT    XSALIM
LABEL     SECONDARY  VALVE  POSITION    INCHES
PRINT     VCA,XSALIM,XCA,DXPS,XPS,XR,DDELFD,DELFD,VZ
END
STOP
```

APPENDIX B

MODEL 2 LISTING

```
TITLE 625734-5479    ELEVON  ACTUATOR  MODEL 2                11.25.75
*     IMPLEMENTATION  MODEL  FREQUENCY  RESPONSE
*   MACRO  FOR  FIRST  ORDER  LIMITED  INTEGRATOR
*     NOTE -  THIS MACRO ONLY LIMITS THE INPUT OF THE INTEGRATOR.
*             THE OUTPUT MUST BE LIMITED IN A NOSORT SECTION AT
*             THE BEGINNING OF THE DYNAMIC SECTION.
*
MACRO     Y =  LINTG1(IC,YDOT,LOLIM,HILIM)
PROCEDURE    DYDT =  LIM1(Y,YDOT,LOLIM,HILIM)
      DYDT =  YDOT
      IF(Y .LE. LOLIM)  DYDT = AMAX1(0.0,YDOT)
      IF(Y .GE. HILIM)  DYDT = AMIN1(0.0,YDOT)
ENDPROCEDURE
      Y  =   INTGRL(IC,DYDT)
ENDMACRO
*
*
*   MACRO  FOR  SECOND  ORDER  LIMITED  INTEGRATOR
*     NOTE -  THIS MACRO ONLY LIMITS THE INPUT TO THE INTEGRATORS.
*             THE OUTPUTS MUST BE LIMITED IN A NOSORT SECTION AT
*             THE BEGINNING OF THE DYNAMIC SECTION.
*
MACRO     Y,YDOT =  LINTG2(IC1,IC1DOT,YDDOT,LOLIM,HILIM)
PROCEDURE    DYDT,D2YDT2 =  LIM2(Y,YDOT,YDDOT,LOLIM,HILIM)
      DYDT  = YDOT
      D2YDT2= YDDOT
      IF(Y .LE. LOLIM)  GO TO 10
      IF(Y .LT. HILIM)  GO TO 11
      DYDT  = AMIN1(0.0,YDOT)
      D2YDT2= AMIN1(0.0,YDDOT)
      GO TO 11
 10   DYDT  = AMAX1(0.0,YDOT)
      D2YDT2= AMAX1(0.0,YDDOT)
 11   CONTINUE
ENDPROCEDURE
      YDOT =  INTGRL(IC1DOT,D2YDT2)
      Y    =  INTGRL(IC1,    DYDT  )
ENDMACRO
```

```
*
*
INITIAL
*
*
*        ELEVON  ACTUATOR  -  IMPLEMENTATION  MODEL
*        ELEVON  ACTUATOR  -  IMPLEMENTATION  MODEL
*        ELEVON  ACTUATOR  -  IMPLEMENTATION  MODEL
*        ELEVON  ACTUATOR  -  IMPLEMENTATION  MODEL
*
*
*****************************************************************************
*****  CONSTANTS AND FUNCTIONS ARE FOR THE OUTBOARD ACTUATOR SYSTEM  ***
*****************************************************************************
CONST    AP=2.781E-2,         APS=1.930E-1,        AR=18.02
CONST    FL=1.500E4,          BETA=1.71765,        BPS=1.346
CONST    CL=1.080E-8,         COUL=11.6
CONST    CD=4.550
CONS     DELEIN=1.000
CONS     FRAM=1.550E4,        FTAPP=1.452E3
CONST                         HPL=1.258E2
CONST    IE=2.680E3,          IL=8.600E0
CONST    KA=1.500E1
CONST    KASA=0.352712,       KH=3.190E-3,         KC=1.710E.
CONST    KDELE=1.0
CONST    KFR=1.173E0,         KPS=7.47917E-6,      KPT=1.670E-3
CONST    KQPS=51.80,          KQS=4.9769,          KS=1.340E3
CONST    KT=1.2858E5,         KIM=4.500E-2,        KXPS=6.22 E0
CONST    K0=4.240E0,          K1=1.8476E-1,        K2=5.220E-2
CONST    K12=1.494E-1,        K22=4.460E-2
CONST    L=1.0E-3,            LAP=1.100E-3
CONST    LN=1.653E-2,         LXPS=6.500E-2
CONST    MPS=2.070E-3,        PSS=3.000E3
CONST    P3=0.0,        P4=(15.0,20.0,25.0)  ,   P5=0.0
CONST    RAD=57.2958
CONST    ZAERO=0.00,          TAUC=1.000E-1,       TDT=4.000E-3
CONST    VT2=8.200E-1,                             WD=3.140E2
CONST    ZDS=1.000E-3,        ZLS=1.000E-3,        ZETAC=7.070E-1
   FUNCTION  MOMENT  =  (-36.5,7.767), (-35.0,7.884), ...
```

```
          (-30.0,8.223), (-25.0,8.441), (-20.0,8.661), ...
          (-15.0,8.766), (-10.0,8.800), (-7.705,8.793),...
          (-5.00,8.767), ( 0.00,8.671), ( 5.00,8.517), ...
          ( 10.0,8.307), ( 15.0,8.047), ( 20.0,7.740), ( 21.5,7.639)

    FUNCTION  STROKE  =  (-36.5,-4.266),(-35.0,-4.061),...
          (-30.0,-3.358),(-25.0,-2.628),(-20.0,-1.860),...
          (-15.0,-1.119),(-10.0,-0.352),(-7.705,0.000),...
          (-5.00, 0.418),( 0.00, 1.176),( 5.00, 1.927),...
          ( 10.0, 2.661),( 15.0, 3.375),( 20.0, 4.064),( 21.5, 4.266)
DYNAMIC
NOSORT
      XQ= LIMIT(-LXPS,LXPS,XQ)
      XPS= LIMIT(-LXPS,LXPS,XPS)
      XR= LIMIT(-5.442, 3.090, XR)
      DELE= LIMIT(-0.437045,0.375245,DELE)
SORT
*
*  ASA INPUT AND TORQUER MOTOR
*
*   THE ASA OUTPUT IS RATE LIMITED TO 20 DEGREES/SECOND
      CMDELE= DELEIN*SINF(P3,P4,P5)
      DELINC= AFGEN(STROKE,CMDELE)
      VC1 = (DELINC-1.176)*KFB

      IA= (VC1-VZ)*KA - VK
      I =  LIMIT(-IL,IL,IA)
         H =  0.02 + (0.16/7.6)*ABS(I)
      ILIM=  HSTRSS(0.0,-H,H,I)
      TC =  KTM*ILIM
*
*  FLAPPER AND SECOND STAGE VALVE
*
      ETA =  TC - KPS*P1 - KXPS*XPS
      AQL = ABS(QL)
      PSP =  PSS - (KA+K12*AQL+K22*AQL*AQL)
      PVS =  PSP - P1*SIGN(1.0, XS)
      XFA= LIMIT(-0.0016,0.0016,ETA*LN)
      XSE= XFA*KQS
```

```
      XSP= KPS*F1
      XS= LIMIT(-0.01E.,.015,XSF-XSP)
      QSA= XS*CC*SIGN(SQRT(ABS(PVS)),PVS)
      XQD= QSA/AP
      XQ= LINTG1(0.0,XQD,-LXPS,LXPS)
      F1= 4.0*BETA*APS*APS*(XQ-XPS)/V12
      P1 =  F1/APS
*
*   MOD PISTON DYNAMICS
*
      PS =  PSS - (K0+K1*AQL+K2*AQL*AQL)
      PV =  PS - PL*SIGN(1.0,XPS)
      XPSDSP= DEADSP(-L,L,XPS)
      FBB= PV*KP*XPSDSP
*   THE FOLLOWING  TWO STATEMENTS COMPUTE THE STICTION  FORCE
      FCOUL1=  DEADSP(-COUL,COUL,(4.0*F1)-FBB)
      FCOUL =  FCNSW(XPSD,-COUL,FCOUL1,COUL)
      FTOT= (4.*F1) - FBB - FCOUL
      XPSDD= (FTOT-APS*XPSD)/MPS
       XPS,XPSD= LINTG2(0.0, 0.0, XPSDD, -LXPS, LXPS)
*
*   LOAD FLOW EQUATIONS
*
      ZD =  DEADSP(-ZDS,ZDS,XPS)
      ZL =  LIMIT(-ZLS,ZLS,XPS)
* IMPLICIT LOOP FOR QL
      QL =  IMPL(0.0,0.01,FQQL)
      AQL1 =  ABS(QL)
      PS1 =  PSS-(K0+(K1+K2*AQL1)*AQL1)
      PV1 =  PS1 - PL*SIGN(1.0, XPS)
      QPAR1=  KCPS*ZD*SIGN(SQRT(ABS(PV1)),PV1)
      QLAM1=  2.0*CL*(PS1*ZL-LAP*FL)/(LAP**2-ZL**2)
      FQQL =  QLAM1+ QPAR1
      QPAR =  KCPS*ZD*SIGN(SQRT(ABS(PV )),PV )
      QLAM =  2.0*CL*(PS *ZL-LAP*FL)/(LAP**2-ZL**2)
*
*  RAM PISTON
*
      XRD = QL/AR
```

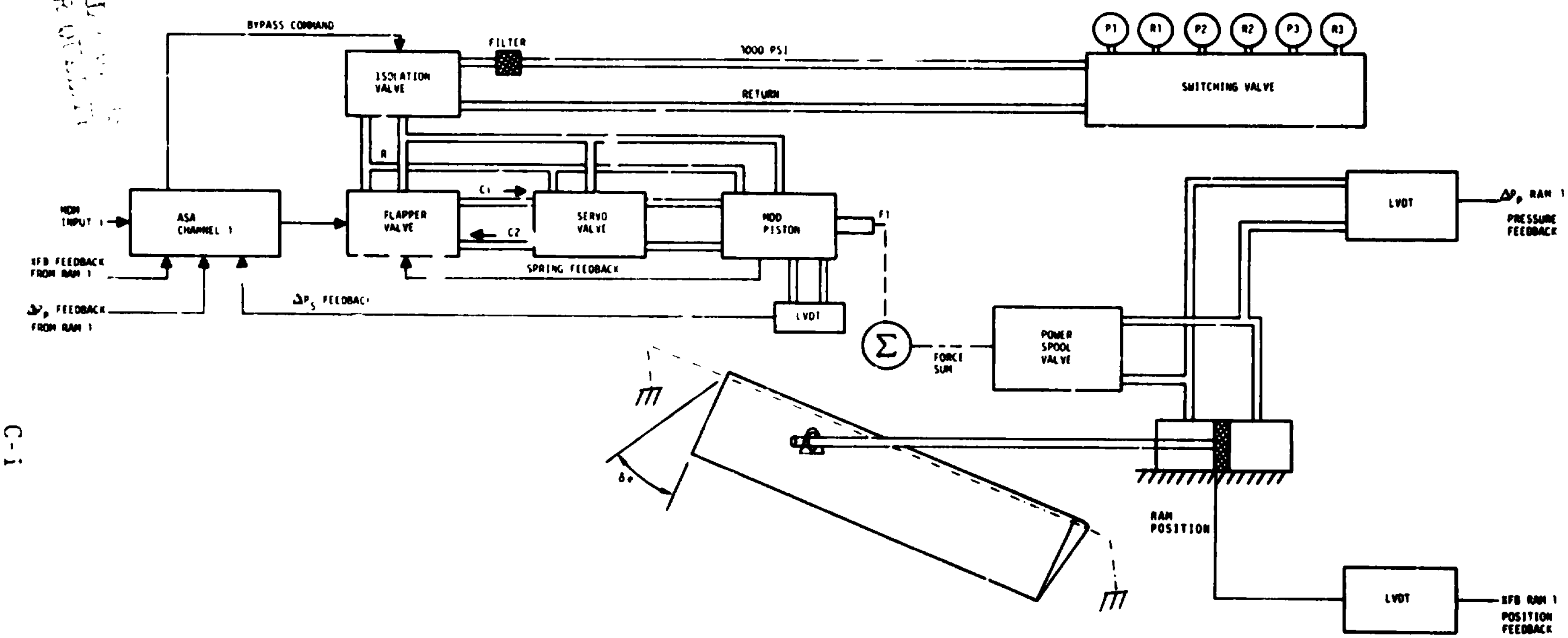
```
      XR= LINTGI(0.0,XRD,-5.442,3.090)
      FL =  KT*(XR-XSTR)
      PL =  FL/AR
      MR= AFGEN(MOMENT,DDELE)
      TR =  MR*FL
      TDELE =  DELE*KDELE

*  THE FOLLOWING PROCEDURE COMPUTES THE TOTAL TORQUE INCLUDING
*   THE EFFECTS OF ACTUATOR STICTION AND ELEVON STICTION.
      FFXFB= FTXFB*MR
PROCEDURE     TTOT= STICTN(DELED,XFBD,FRAM,FFXFB,TR,TAERO,TDELE)
      TLIMIT= FRAM+FFXFB
      T1= TR+TAERO-TDELE
      T2= FCNSW(XFBD,-FFXFB,0.0,FFXFB)
      T3= FCNSW(DELED,-FRAM,0.0,FRAM)
         IF(XFBD .NE. 0.0)  GO TO 20
            IF(DELED .NE. 0.0)  GO TO 12
*           TO HERE IF XFBD.EQ.0  AND  DELED.EQ.0
            TTOT= DEADSP(-TLIMIT,TLIMIT,T1)
            GO  TO  40
*           TO HERE IF XFBD.EQ.0  AND  DELED.NE.0
 12         TTOT= DEADSP(-FFXFB,FFXFB,T1-T3)
            GO  TO  40
 20      CONTINUE
            IF(DELED .NE. 0.0)  GO TO 30
*           TO HERE IF XFBD.NE.0  AND  DELED.EQ.0
            TTOT= DEADSP(-FRAM,FRAM,T1-T2)
            GO  TO  40
*           TO HERE IF XFBD.NE.0  AND  DELED.NE.0
 30         TTOT= T1-T2-T3
 40   CONTINUE
ENDPROCEDURE

       DELED =  REALPL(0.0,IE/BE,TTOT/BE)
      DDELED= DELED*RAD
      DELE= LINTGI(0.0,DELED,-0.637045,0.375245)
      DDELE =  DELE*RAD
      STR  =  AFGEN(STROKE,DDELE)
      XSTR =  STR - 1.1760
```

```
      XFH  =  XSTH + FL/KS
      XFHD =  DERIV(0.0,XFH)
*
*  TRANSDUCERS AND DEMODULATORS  OUTPUTS
*

      VX  =  REALPL(0.0,TDT,XFH*KFF)
      VZ  =  CMPXPL(0.0,0.0, ETAD,WD,VX*WD*WD)
      PLF  =  HSTRSS(0.0,-HPL,HPL,PL)
      VPL  =  REALPL(0.0,TDT,PLH*KFI)
      VW  =  CMPXPL(0.0,0.0,ZETAD,WD,VPL*WD*WD)
      VK1  =  LEDLAG(TAUC*KC,TAUC,VW)
      VK2  =  REALPL(0.0,TAUC,VW)
      VK   =  VK1 - VK2

TERMINAL
METHOD  RKSFX
TIMER    DELT=0.00005,OUTDEL=0.005,PRDEL=0.010,FINTIM=2.00

RANGE    XQ,XPSD,XPS,XR,DELC,VC1,VK1,VK,IA,I,ILIM,TC,F1,P1,...
         ETA,DDELE,STC,XSTH,FL,PL,ZC,ZL,GL,AGL,PSP,PVS     ,XDD,...
         XQ,FCOUL,PS,PV,FTOT,XPSD,XPS,XHD,AH,MR,TH,XFH,XFHD,TXFH,...
         TDELF,TFDSLE,TTOT,DELED,DELE,VX,VZ,PLH,VPL,VW,VK2,QPAR,JLAM
LABEL  625/34-5479     ELEVON  ACTUATOR  MODEL 2                    11.25.75
LABEL                   SMALL  SIGNAL  FREQUENCY  RESPONSE
OUTPUT   DDELE,CMDELE
LABEL    ELEVON  POSITION   DEGREES
OUTPUT   DDELED
OUTPUT     I,XFHD
LABEL    ELEVON  RATE   DEGREES/SECOND
OUTPUT   I
LABEL    TORQUER  MOTOR  CURRENT   MILLIAMPS
OUTPUT   XPS
LABEL    POWER  SPOOL  POSITION   INCHES
OUTPUT   GL
LABEL    LOAD  FLOW    CUBIC INCHES / SECOND
OUTPUT   PL
LABEL    LOAD  PRESSURE    LBS/SQUARE INCH
OUTPUT   PS
```

```
LABEL     DROPPED  SUPPLY  PRESSURE     LBS/SQUARE INCH
OUTPUT    P1
LABEL     SECONDARY  DELTA  PRESSURE  FEEDBACK     LBS/SQUARE INCH
OUTPUT    STR,XFB
LABEL     ACTUATOR  POSITION    INCHES
LABEL     ACTUATOR  POSITION  FEEDBACK     INCHES
OUTPUT    XS
LABEL     SECONDARY  VALVE  POSITION     INCHES
PRINT     VC1,XS,XC,XPSD,XPS,XR,DDFLED,DDELE,V2
END
STOP
```

APPENDIX C

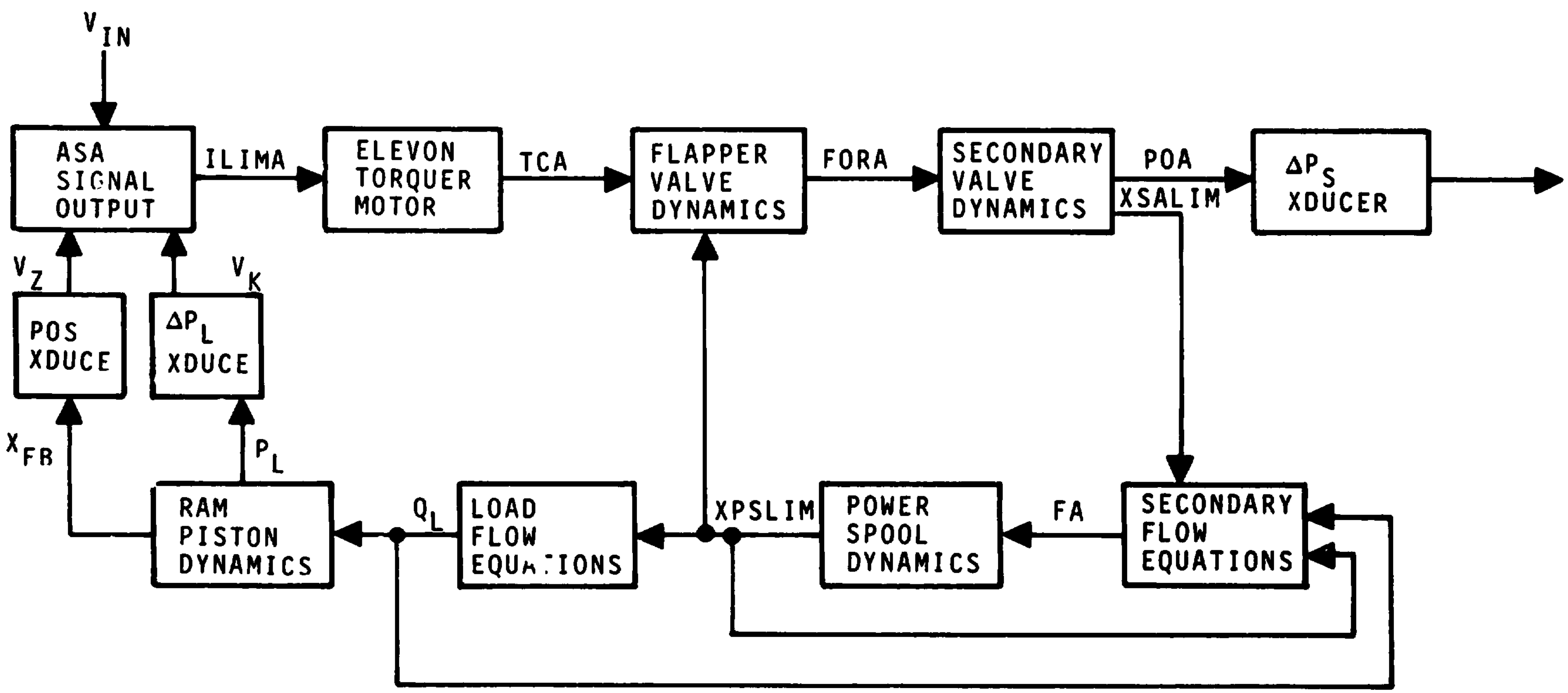
VIEWGRAPHS



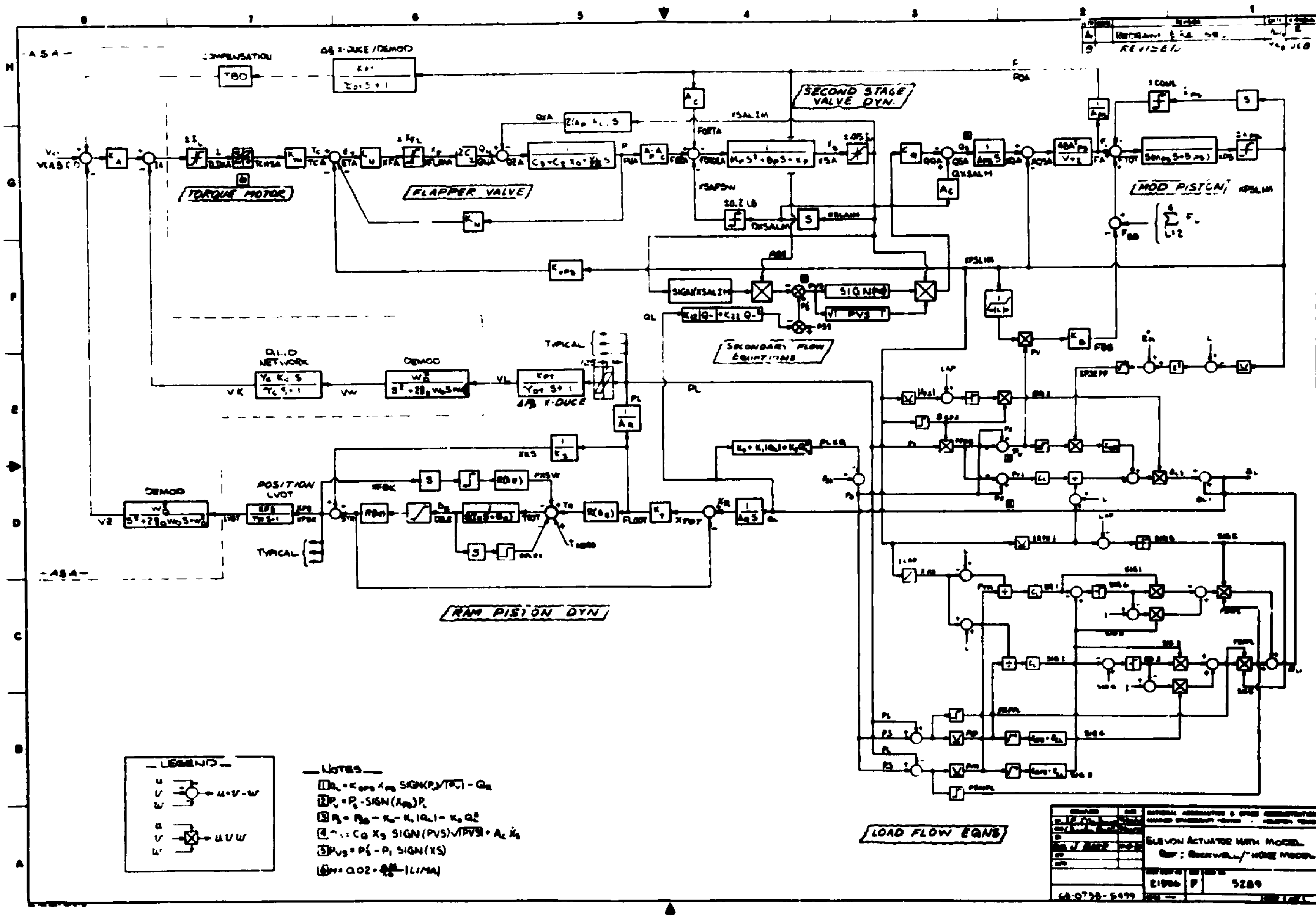
FUNCTIONAL BLOCK DIAGRAM - ELEVON

LEC
12/75

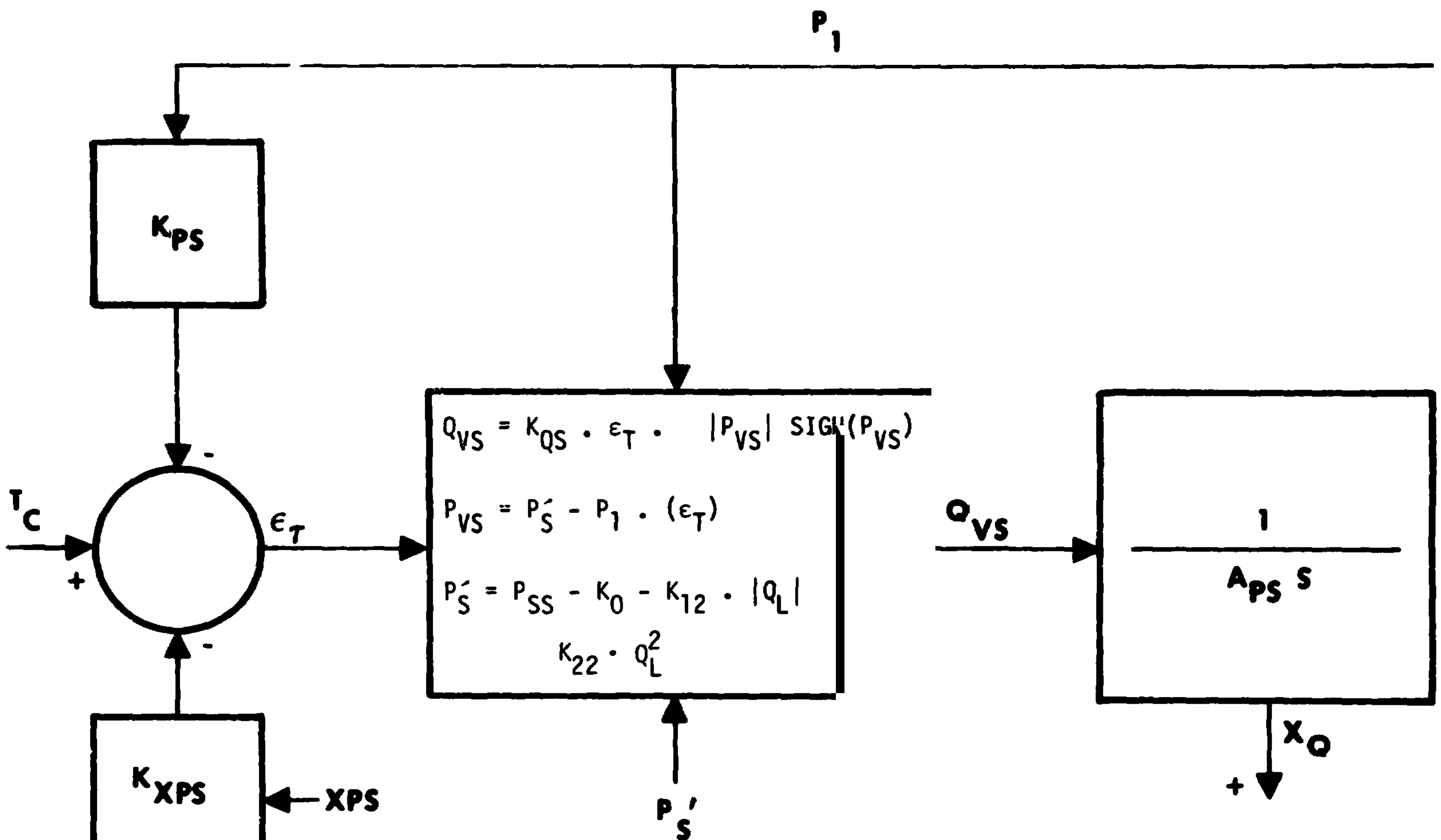
ELEVON ACTUATOR MATH MODEL



LEC
12/75


COMPENSATION
TORQUE MOTOR
FLAPPER VALVE
SECOND STAGE VALVE DYN.
MOD PISTON
SECONDARY FLOW EQUATIONS
DEMOD
POSITION LVDT
TYPICAL
RAM PISTON DYN
LOAD FLOW EQNS
LEGEND
NOTES
ELEVON ACTUATOR MATH MODEL
5289

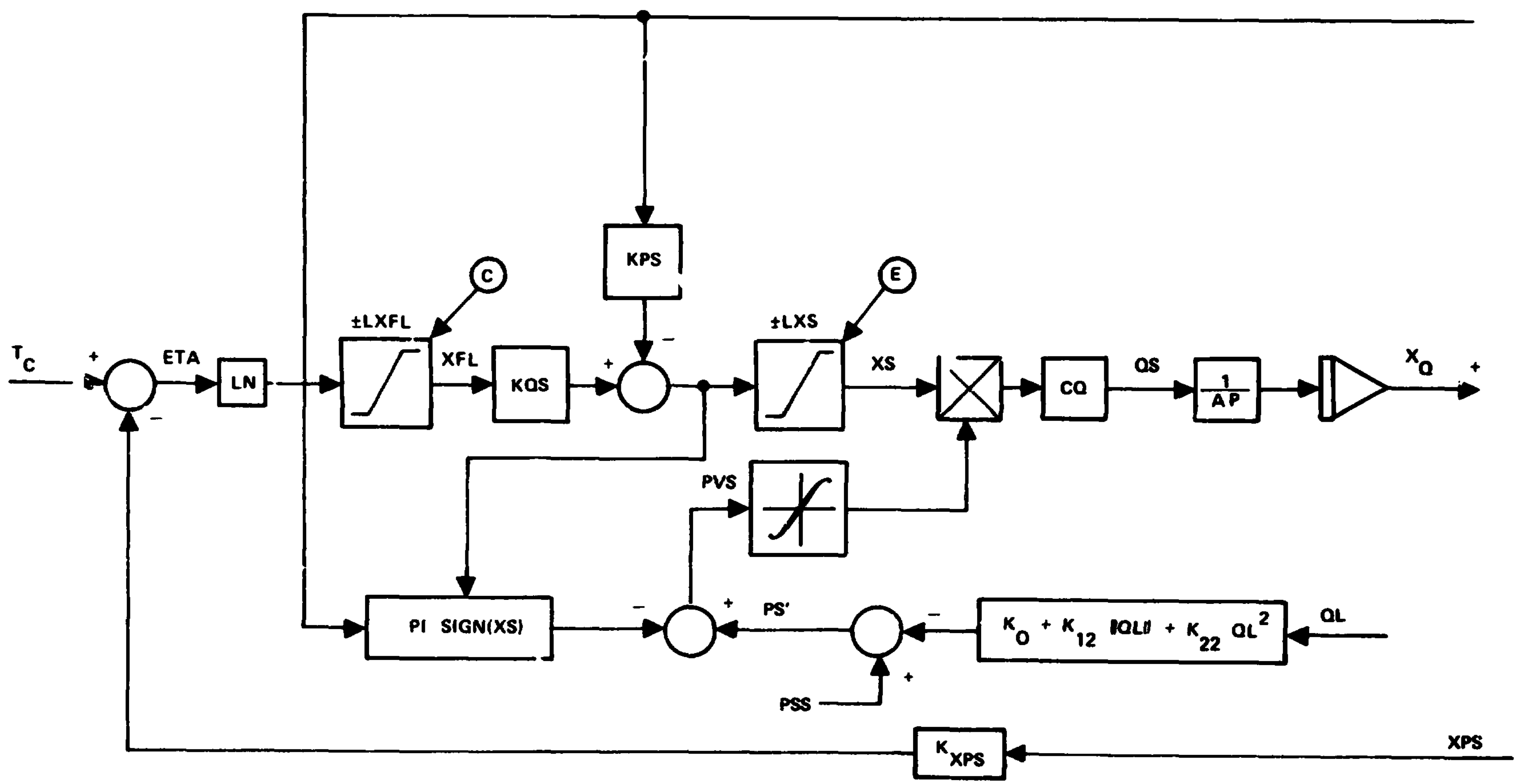
ROCKWELL MODEL 2



SECOND STAGE VALVE

12/75

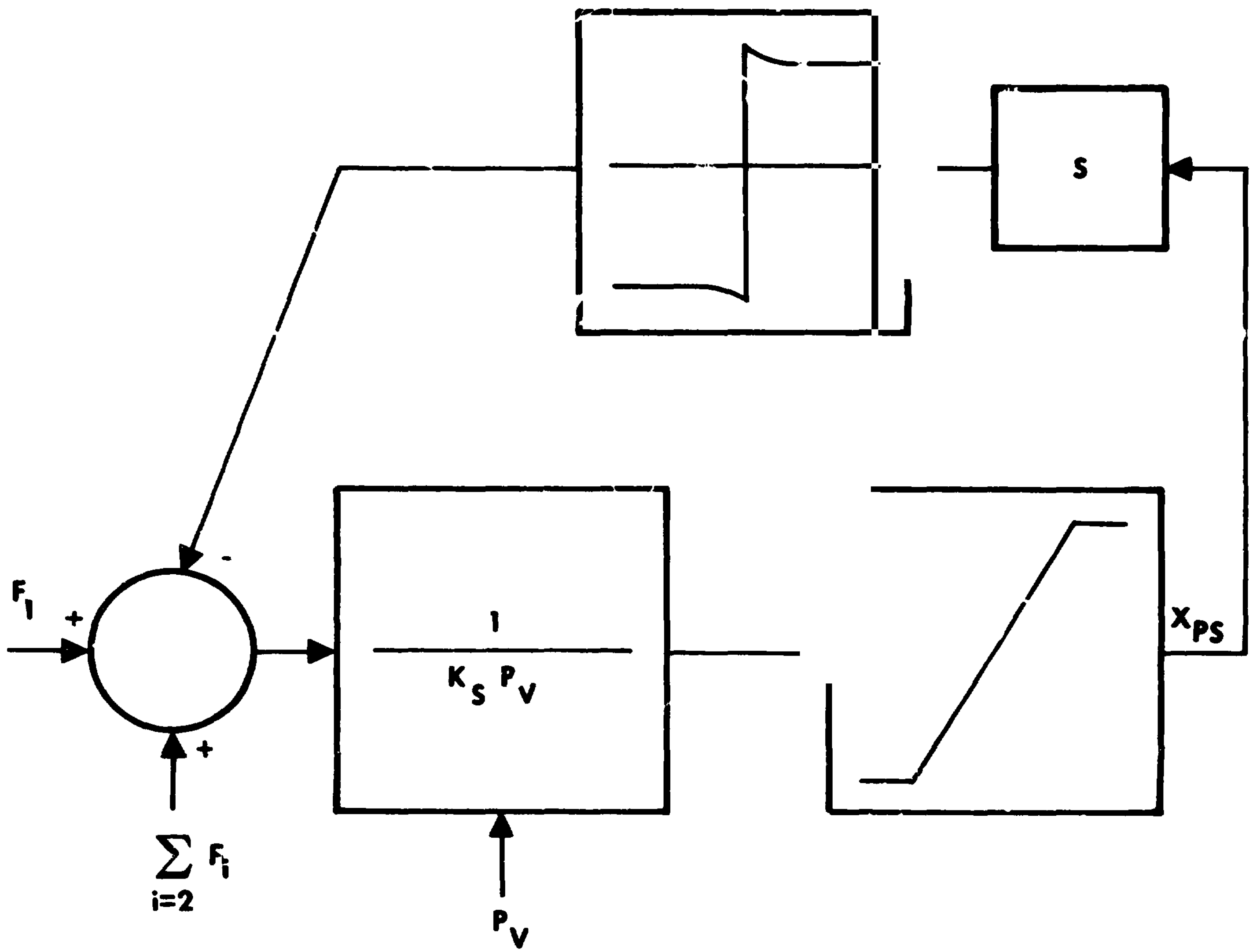
IMPLEMENTATION MODEL



SECOND STAGE VALVE

LEC
12/75

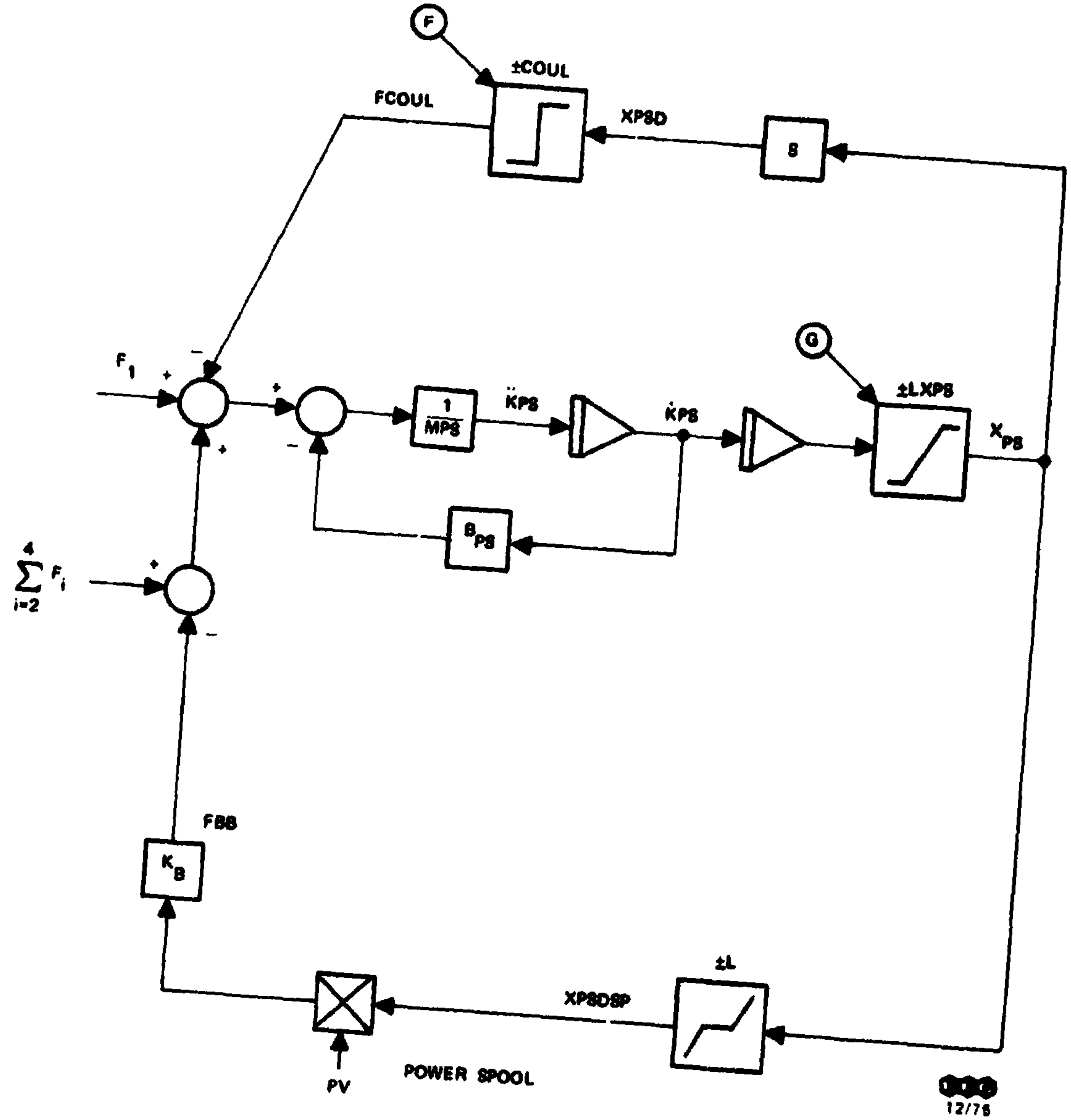
ROCKWELL MODEL 2

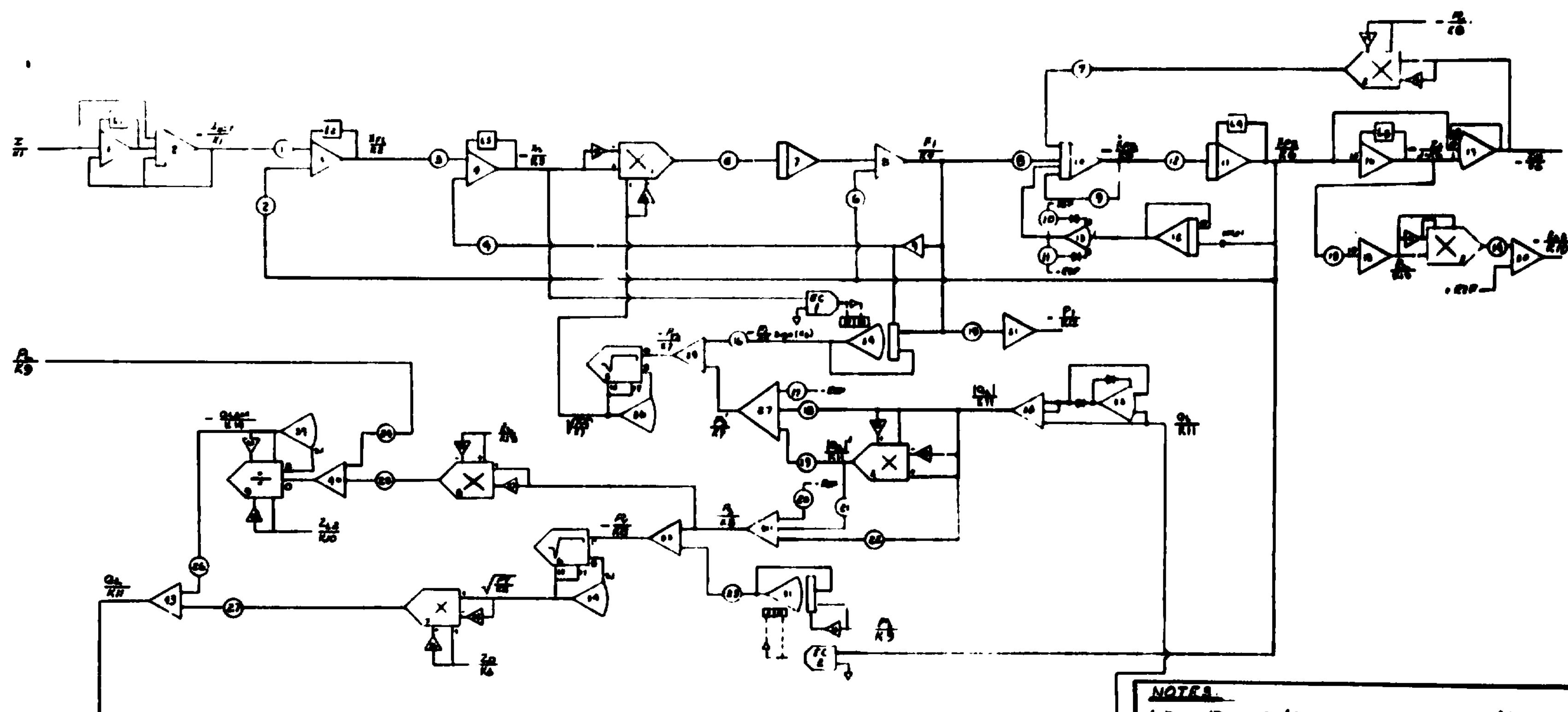


POWER SPOOL

LEC
12/75

IMPLEMENTATION MODEL





Scale Factor	Description	Value	Units
K1	I	8.60	MA
K2	X_{FL}	.0016	IN
K3	X_S	.0150	IN
K4	F_I	150.0	lbs
K5	$\dot{X}_{PS}$	6.20	IN/SEC
K6	X_{PS}	0.068	IN
K7	P_{VS}	3000.	PSI
K8	P_V	3000.	PSI
K9	P_L	3000.	PSI
K10	Z_{LE}	1.000	---
K11	Q_L	100.0	IN^3/SEC
K12	P_I	800.	PSI
K13	Z_L	0.001	IN

Scale Factor	Description	Value	Units
K14	Q_{LAM}	0.320	IN^3/SEC
K15	T_{FOT}	5.0×10^5	IN-lbs
K16	F_L	5.3×10^4	lbs
K17	T_R	5.0×10^5	IN-lbs
K18	T_{AERO}	4.0×10^5	IN-lbs
K19	$\dot{\delta}_e$	100.0	DEG/SEC
K20	δ_e	36.50	DEG
K21	X_{STR}, X_R	4.266	IN
K22	X_{FB}	4.266	IN
K23	V_{PL}	5.000	VOLTS
K24	V_{PFB}	5.000	VOLTS
K25	V_{C1}	5.000	VOLTS
K26	M_R	8.800	IN

NOTES.

1. $P_{V1} = (P_{SS} - SK_7) - [P_1 \, \text{Sgn}(x_B) + SK_{14}|Q_L| + SK_{25}|Q_L|^2]$
2. $P_V = P_S - P_L \, \text{SIGN}(x_{PS})$
3. $P_S = P_{SS} - SK - SK_1|Q_L| - SK_2|Q_L|^2$
4. $Z_{LA} = 1 - (\frac{\delta}{\delta_0})^2$
5. INPUTS ARE T_{AERO} & V_{C1}

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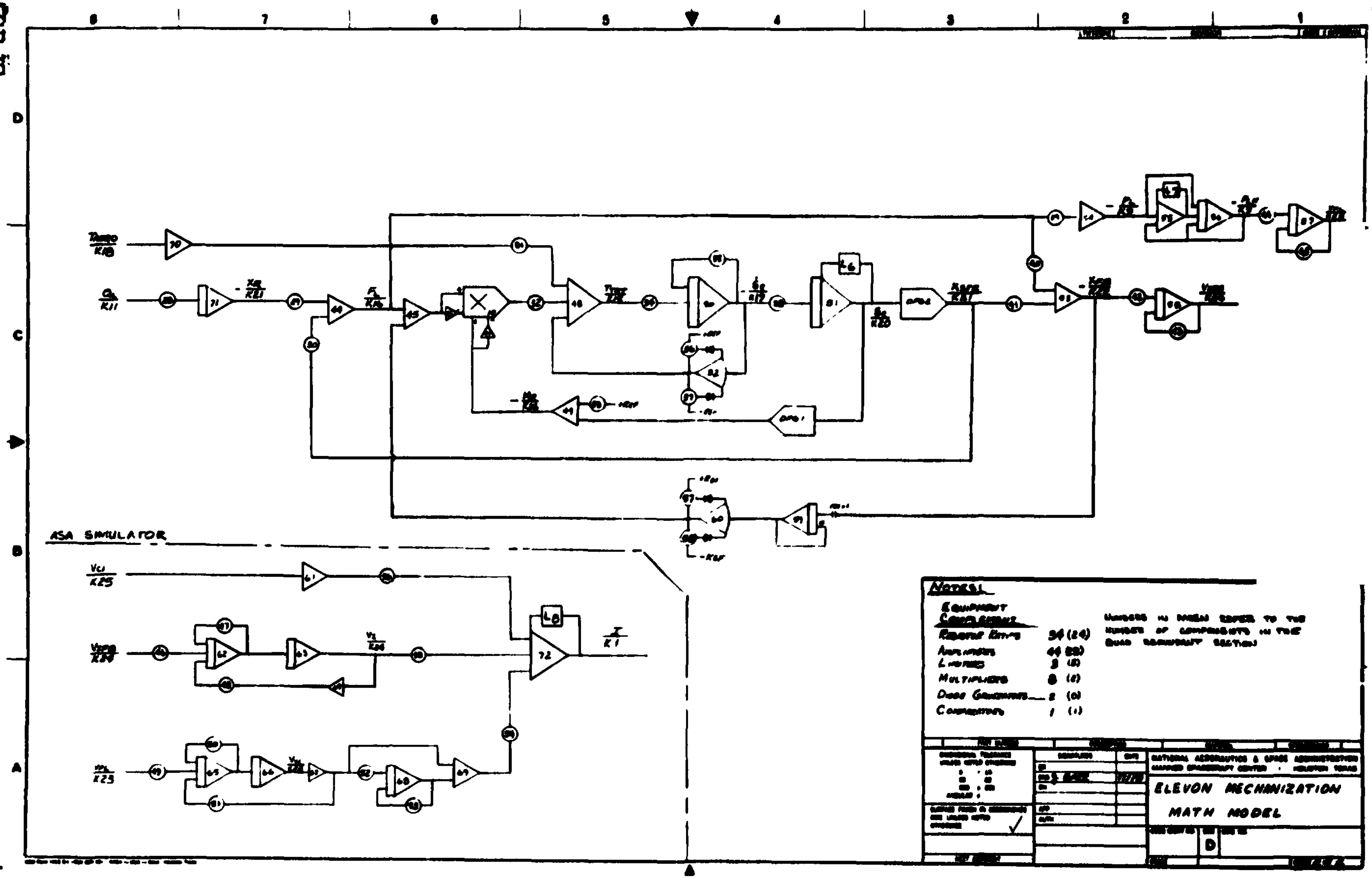
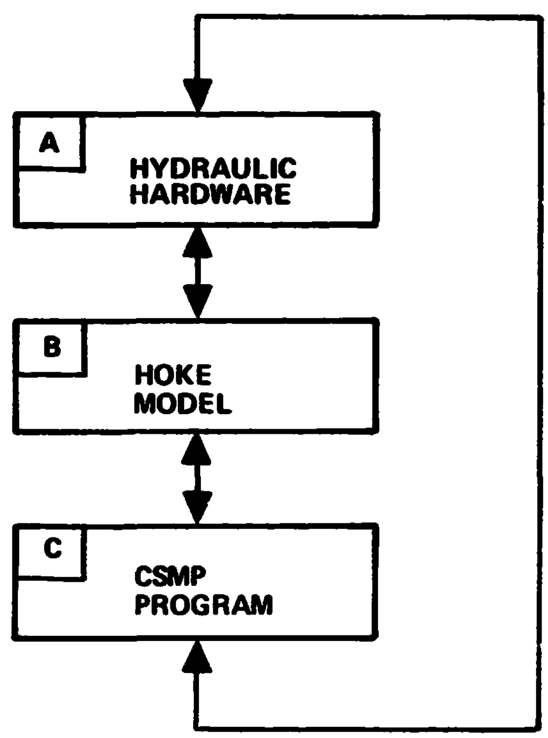
MANNED SPACECRAFT CENTER · HOUSTON TEXAS

ELEVON MECHANIZATION MATH MODEL

D


ASA SIMULATOR
NOTES:
ELEVON MECHANIZATION
MATH MODEL
D

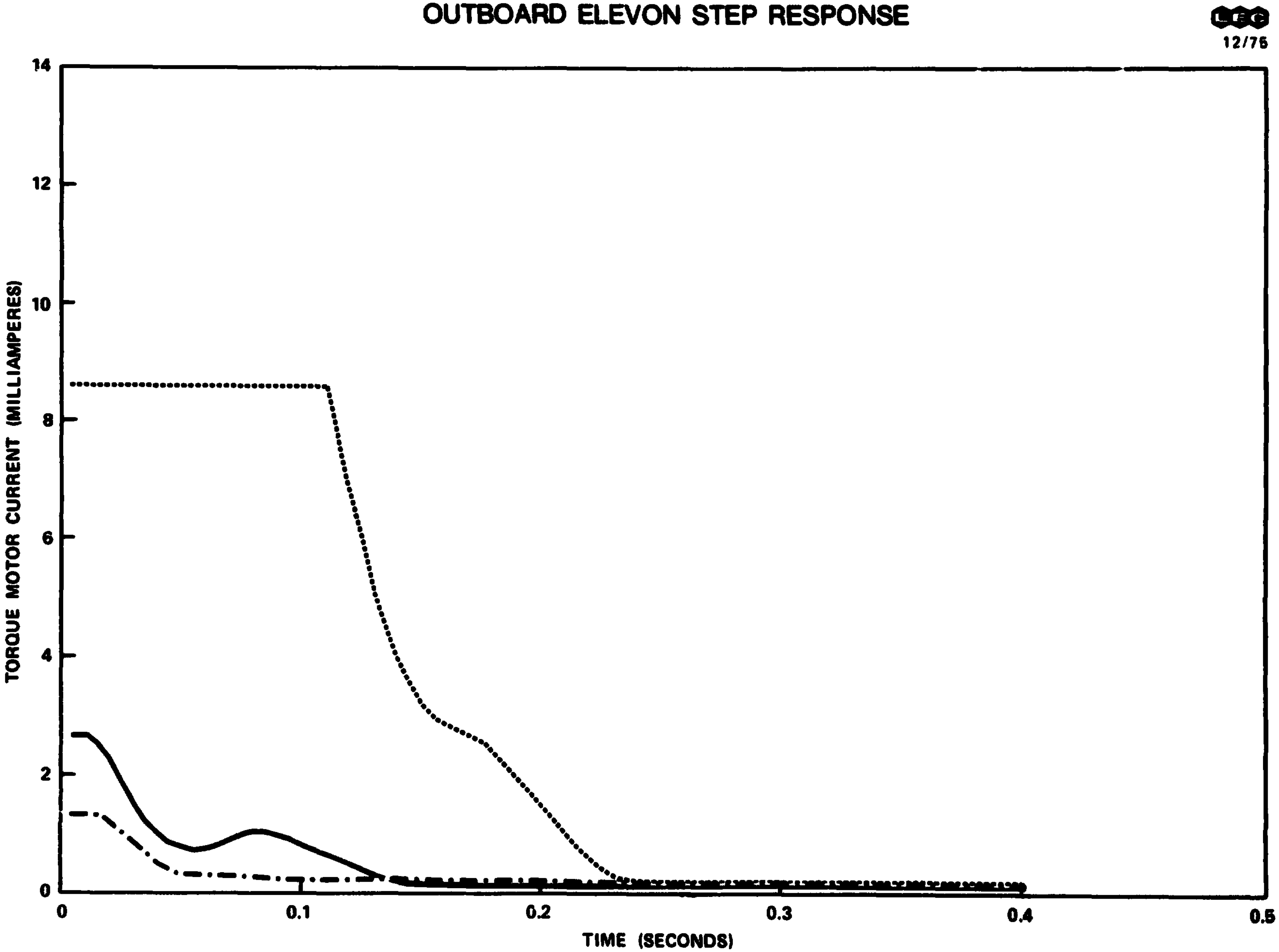


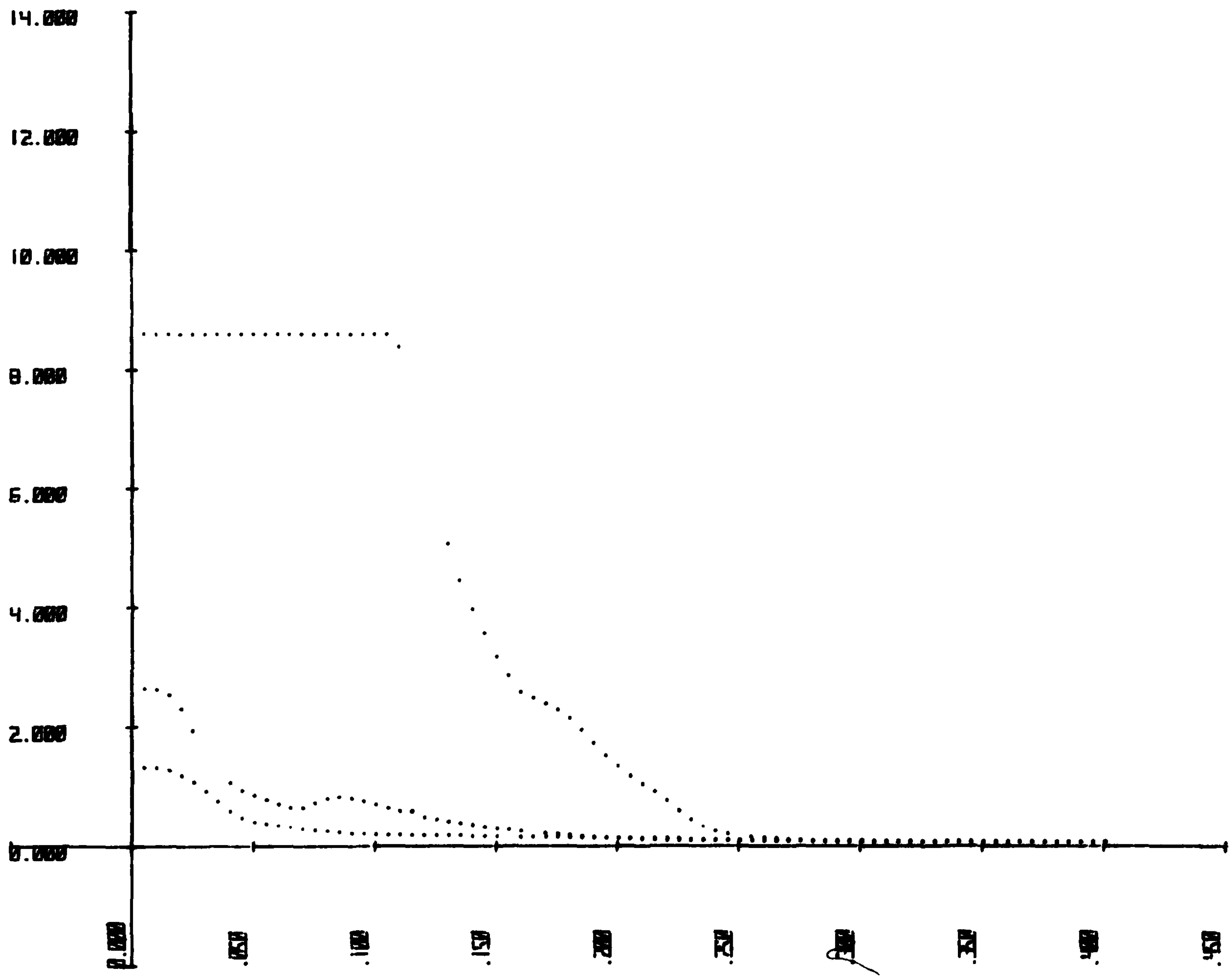
A = B
C = A
$\therefore$
C = B

VERIFICATION METHOD

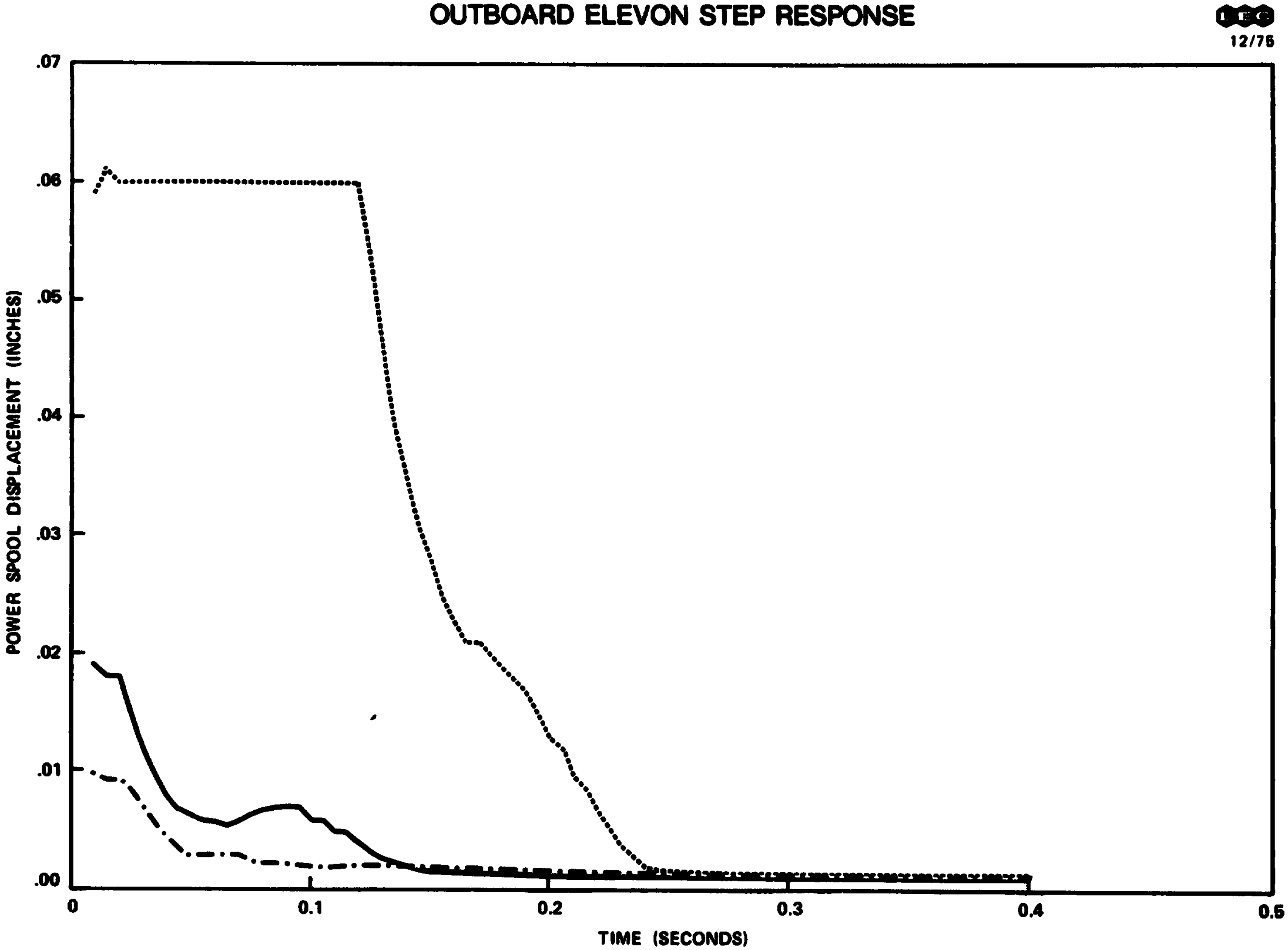
LEC
12/75

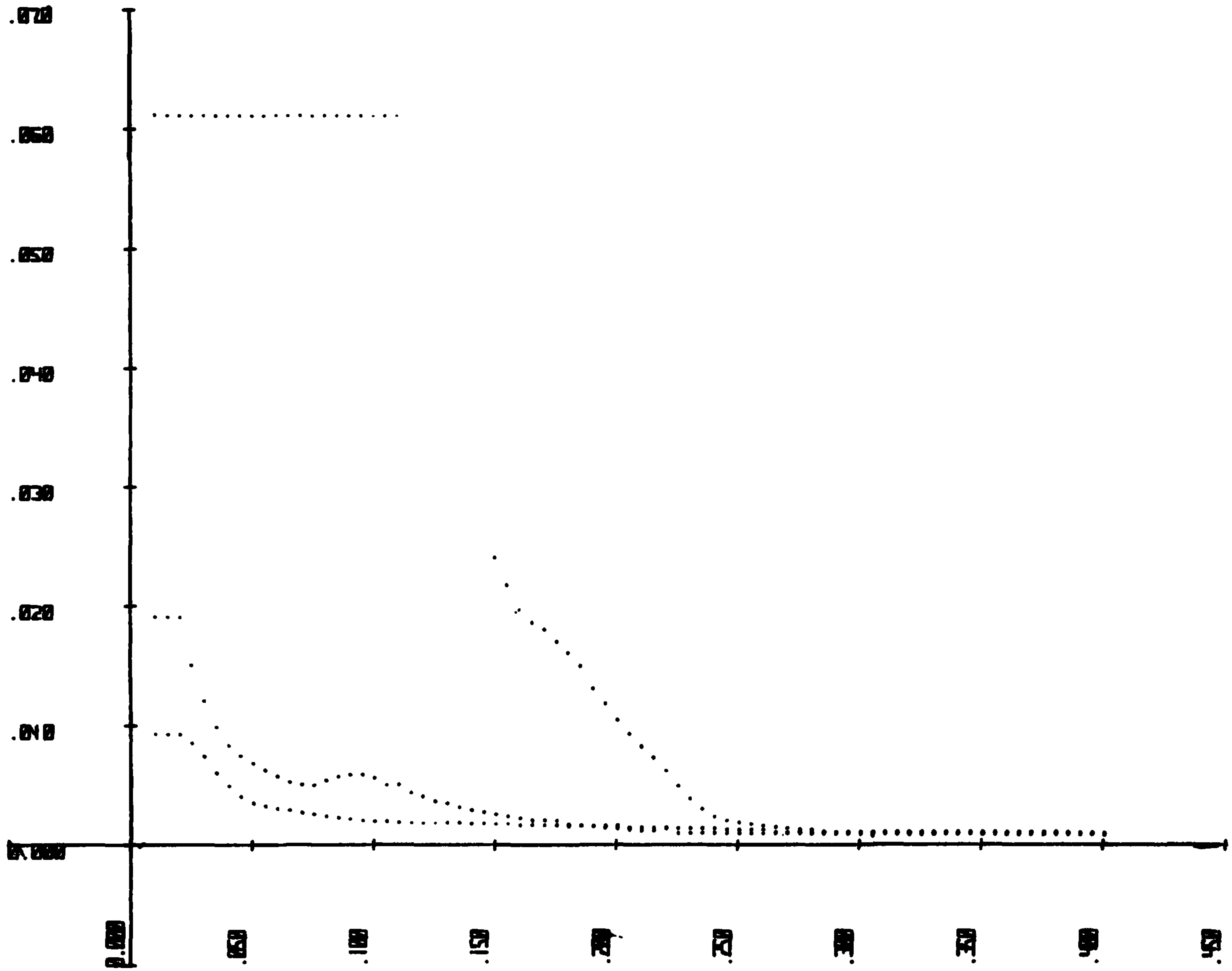
OUTBOARD ELEVON STEP RESPONSE



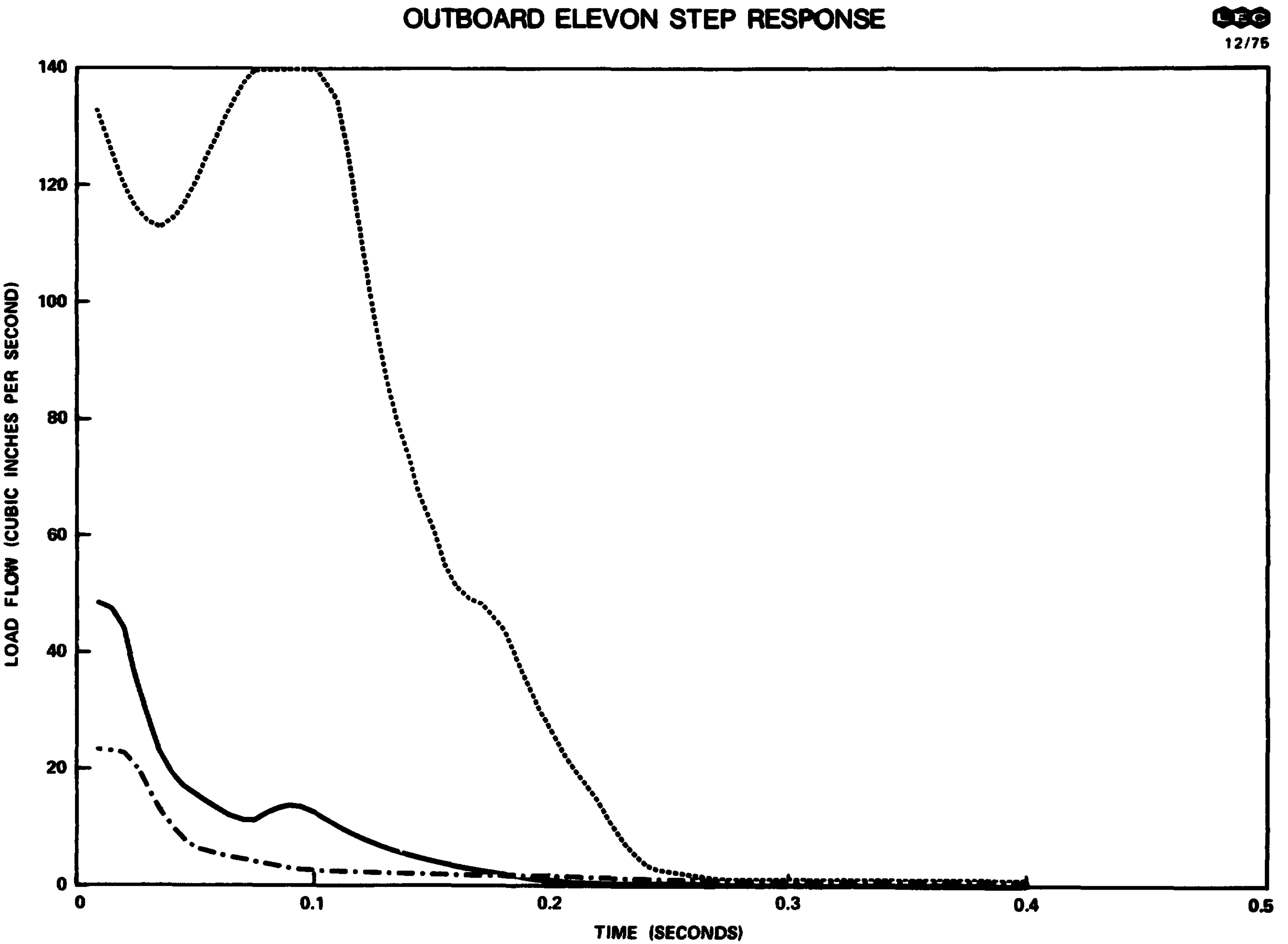

14.000
12.000
10.000
8.000
6.000
4.000
2.000
0.000
0.000
.050
.100
.150
.200
.250
.300
.350
.400
.450

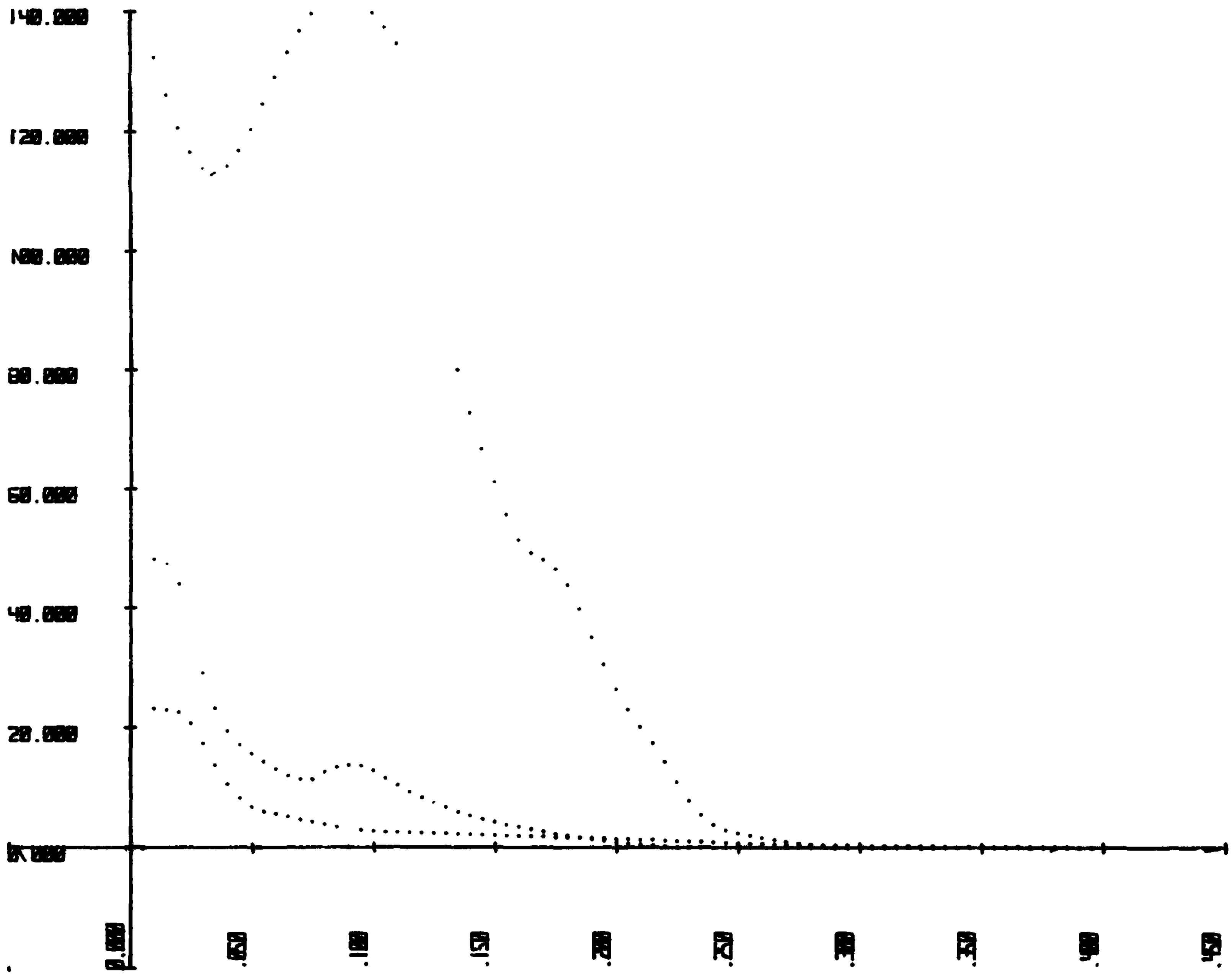
OUTBOARD ELEVON STEP RESPONSE




.070
.060
.050
.040
.030
.020
.010
0.000

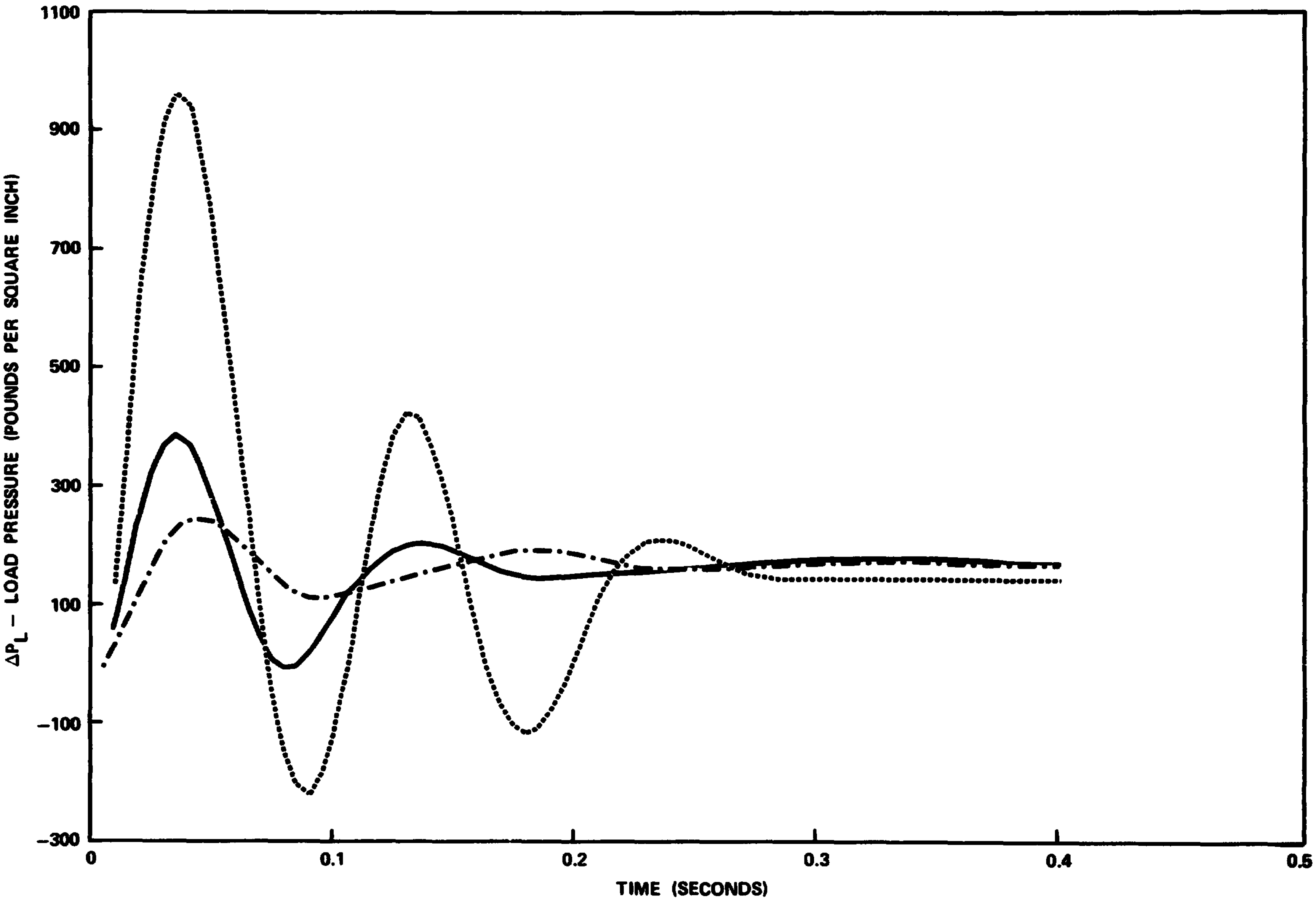
OUTBOARD ELEVON STEP RESPONSE

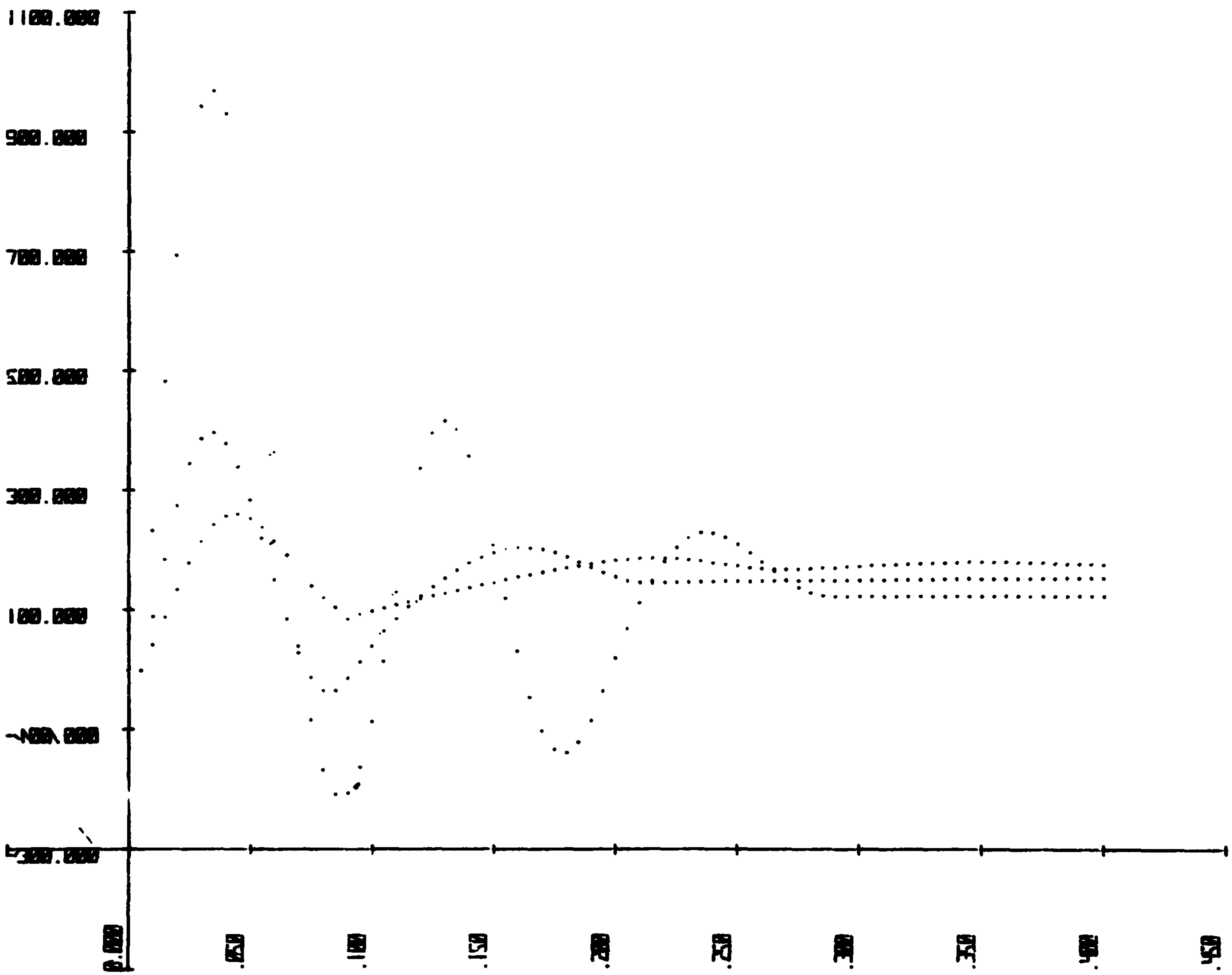


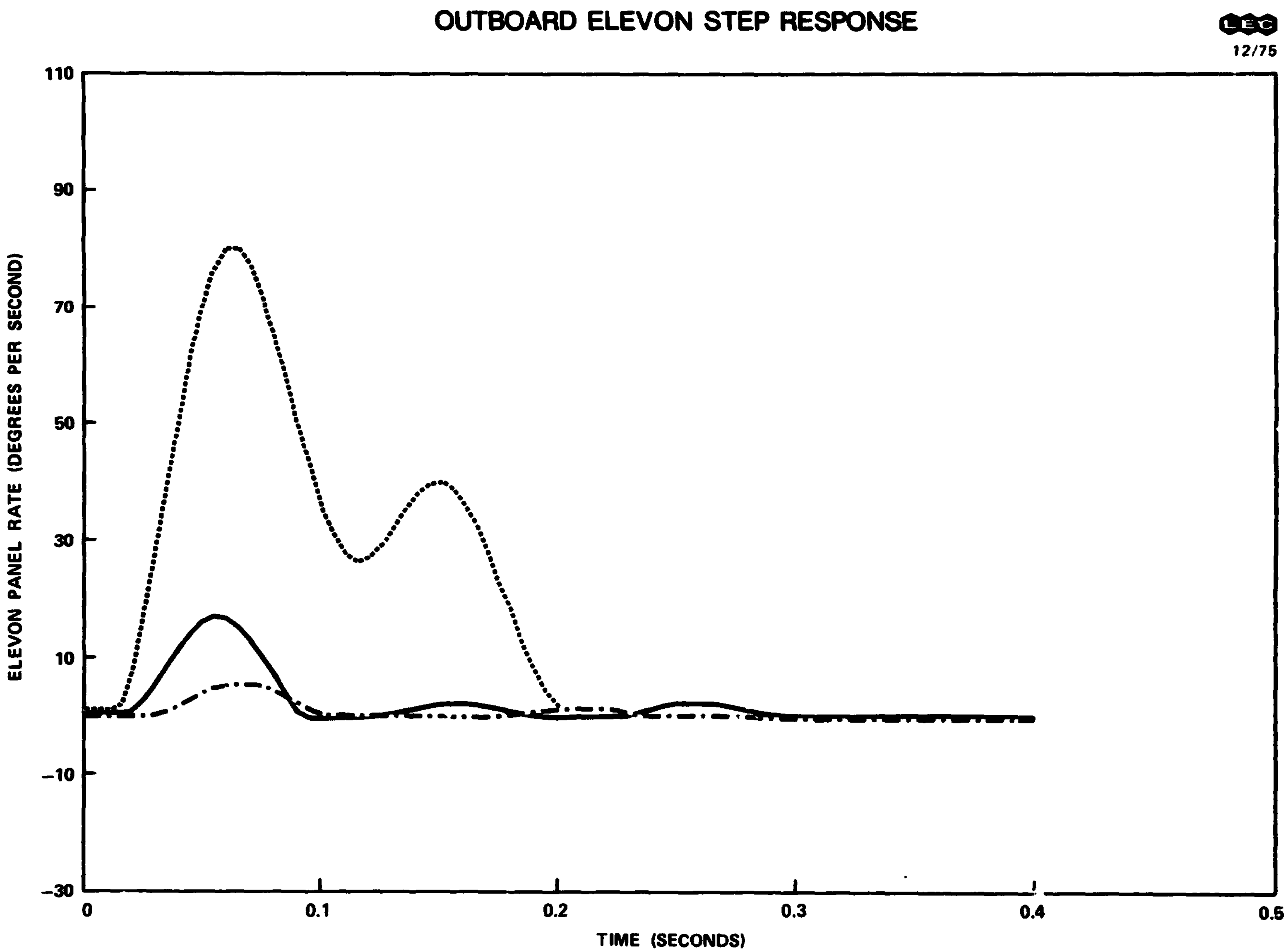

140.000
120.000
100.000
80.000
60.000
40.000
20.000
0.000

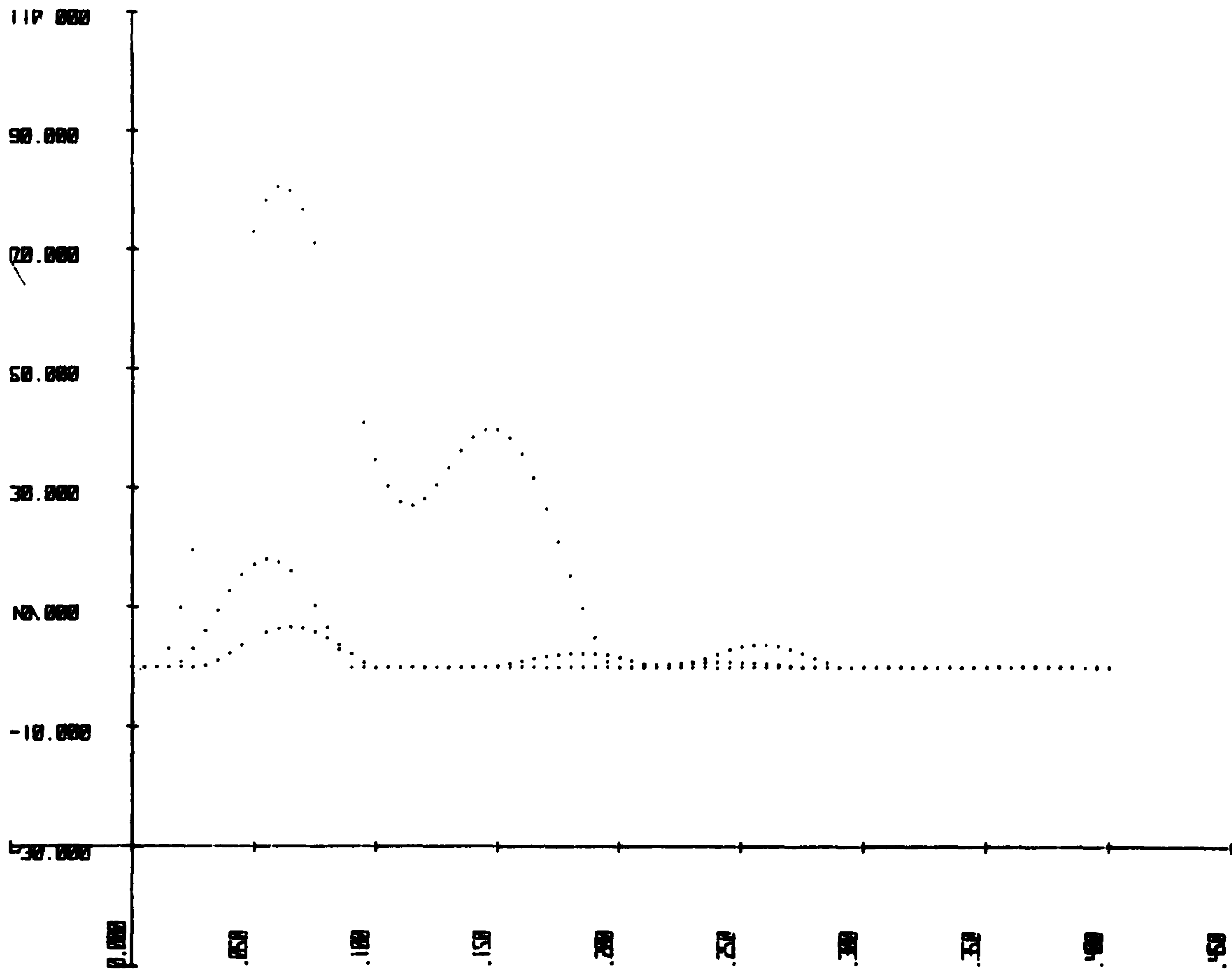
OUTBOARD ELEVON STEP RESPONSE

12/75



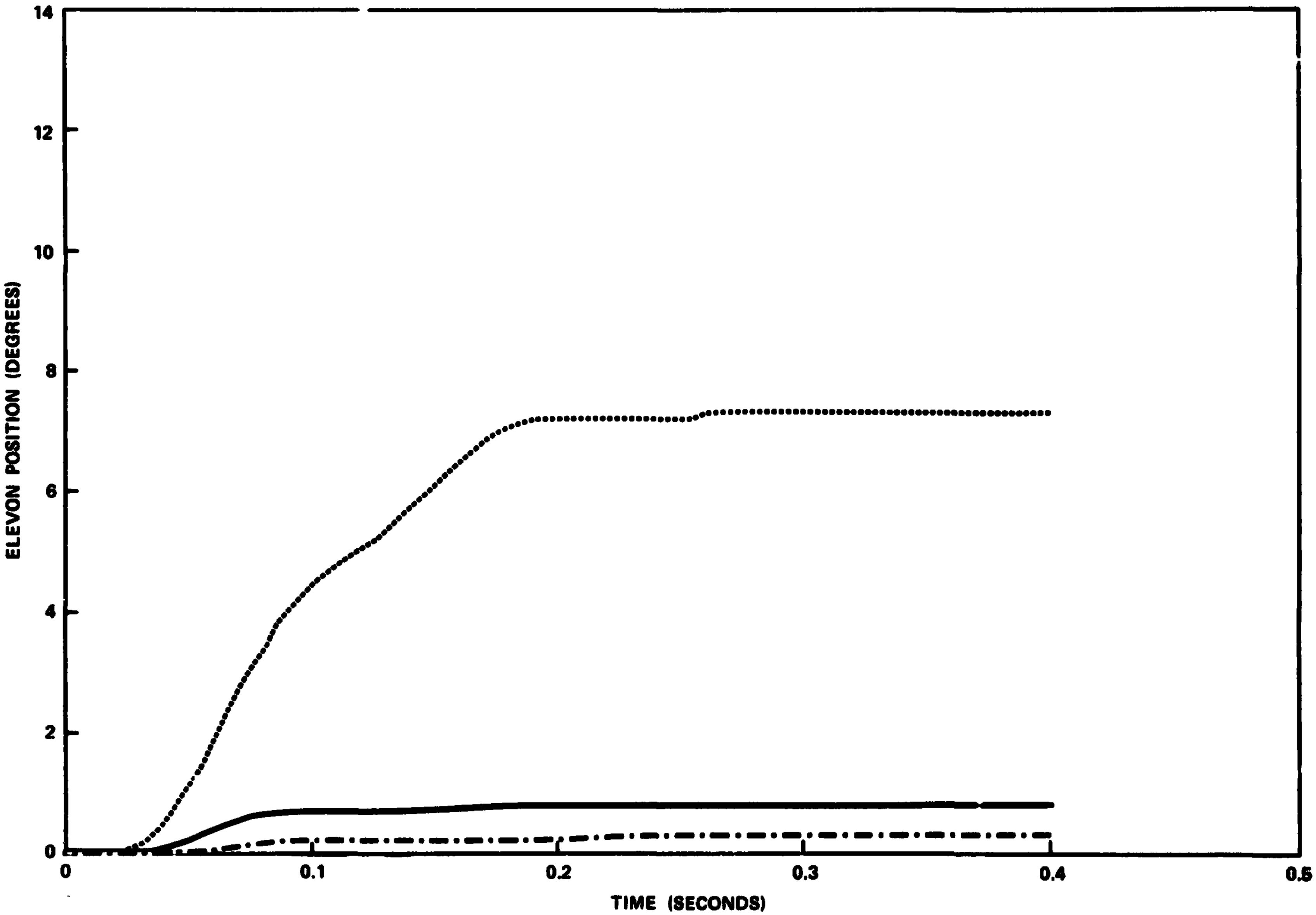

1100.000
900.000
700.000
500.000
300.000
100.000
-100.000
-300.000
0.000
.050
.100
.150
.200
.250
.300
.350
.400
.450

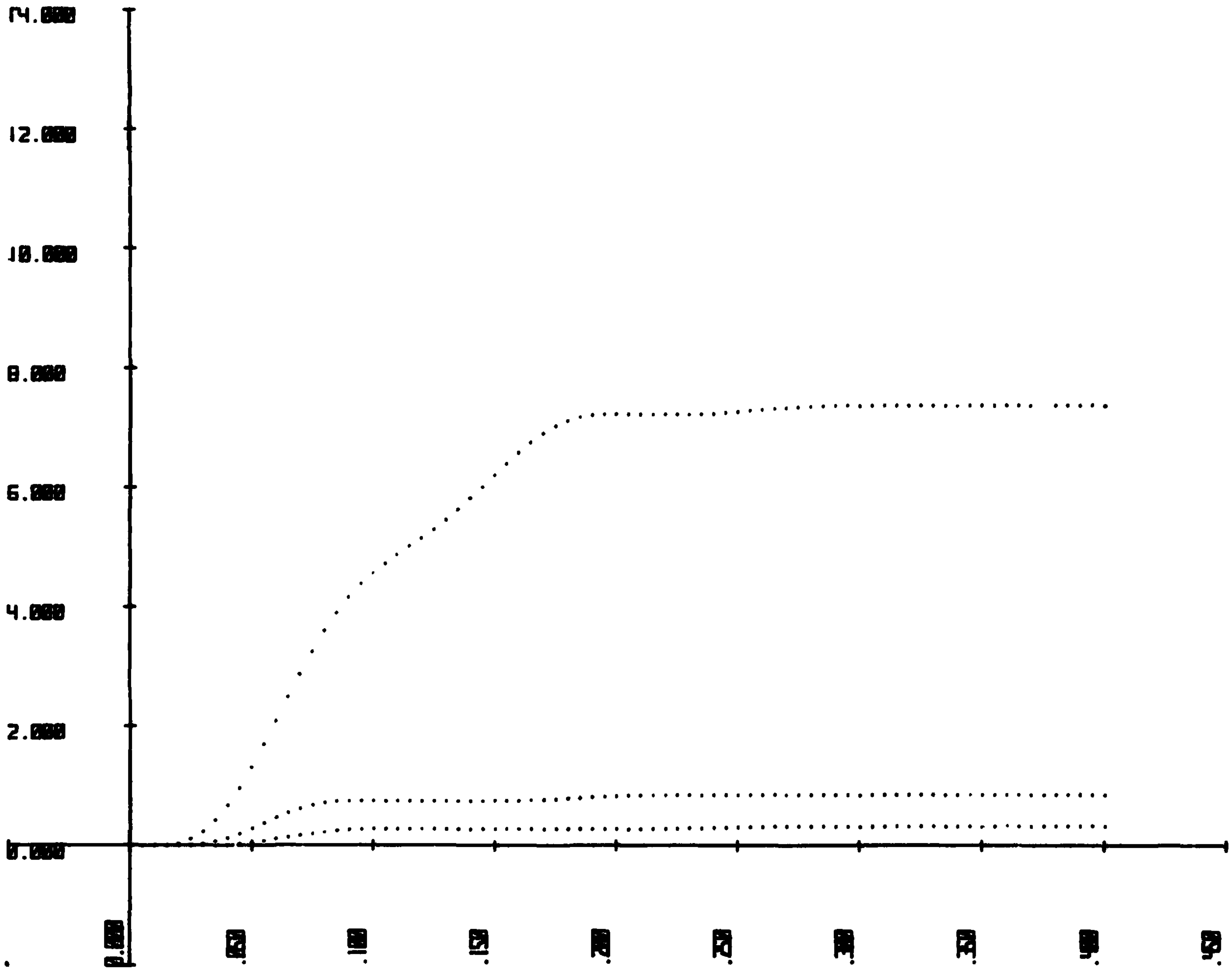

OUTBOARD ELEVON STEP RESPONSE
12/75
ELEVON PANEL RATE (DEGREES PER SECOND)
110
90
70
50
30
10
−10
−30
0
0.1
0.2
0.3
0.4
0.5
TIME (SECONDS)


90.000
70.000
50.000
30.000
-10.000
-30.000

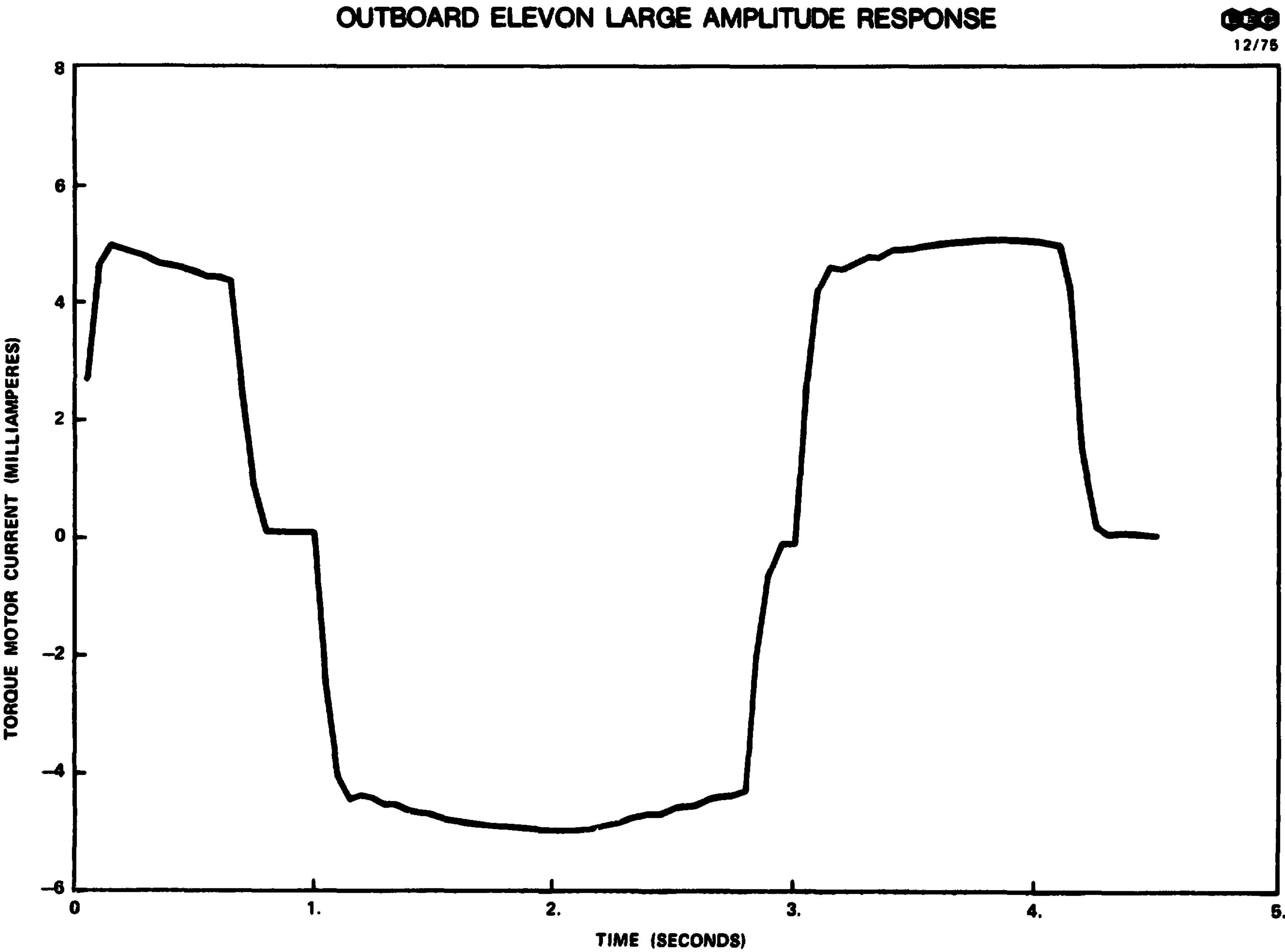
OUTBOARD ELEVON STEP RESPONSE

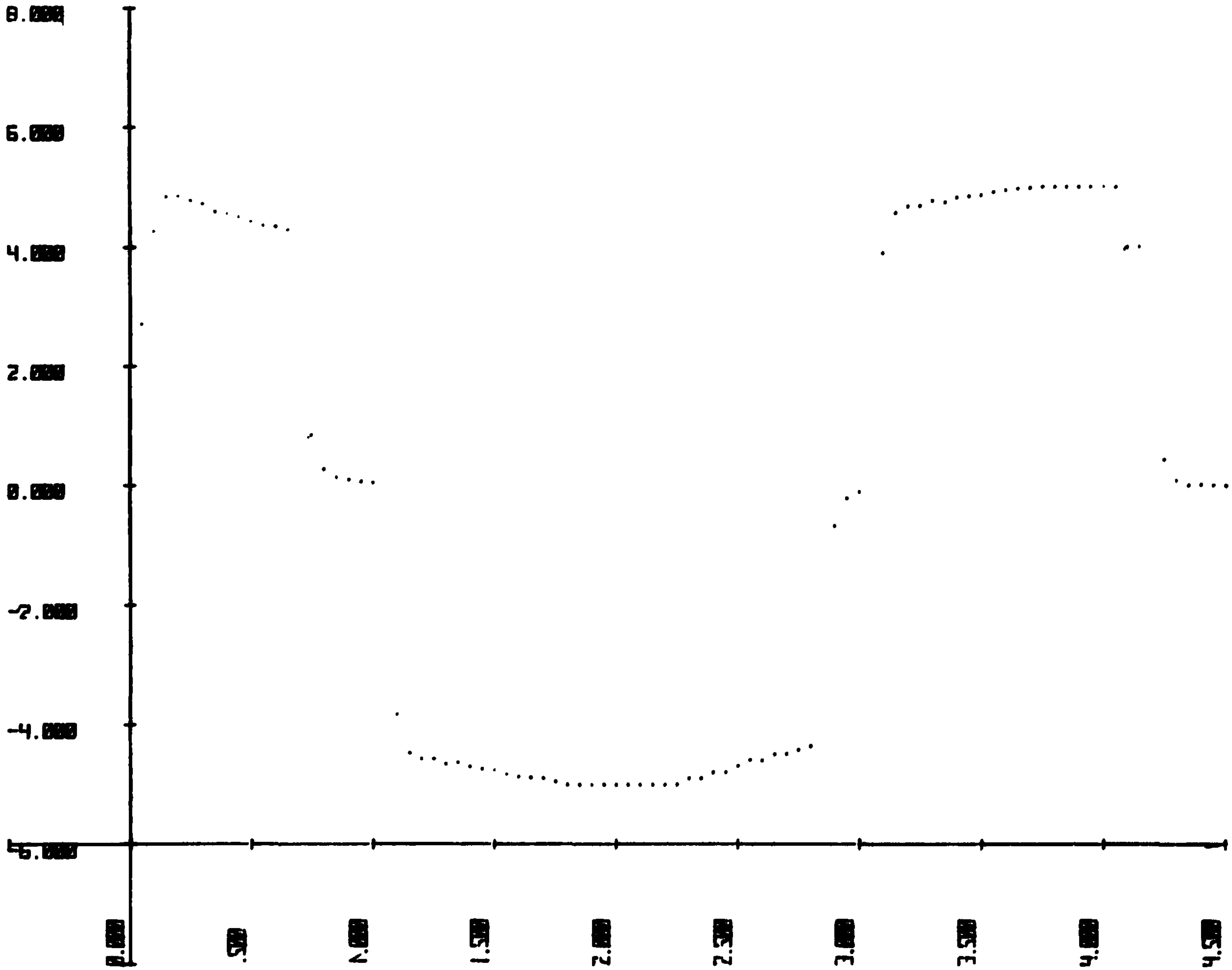
12/75




14.000
12.000
10.000
8.000
6.000
4.000
2.000
0.000

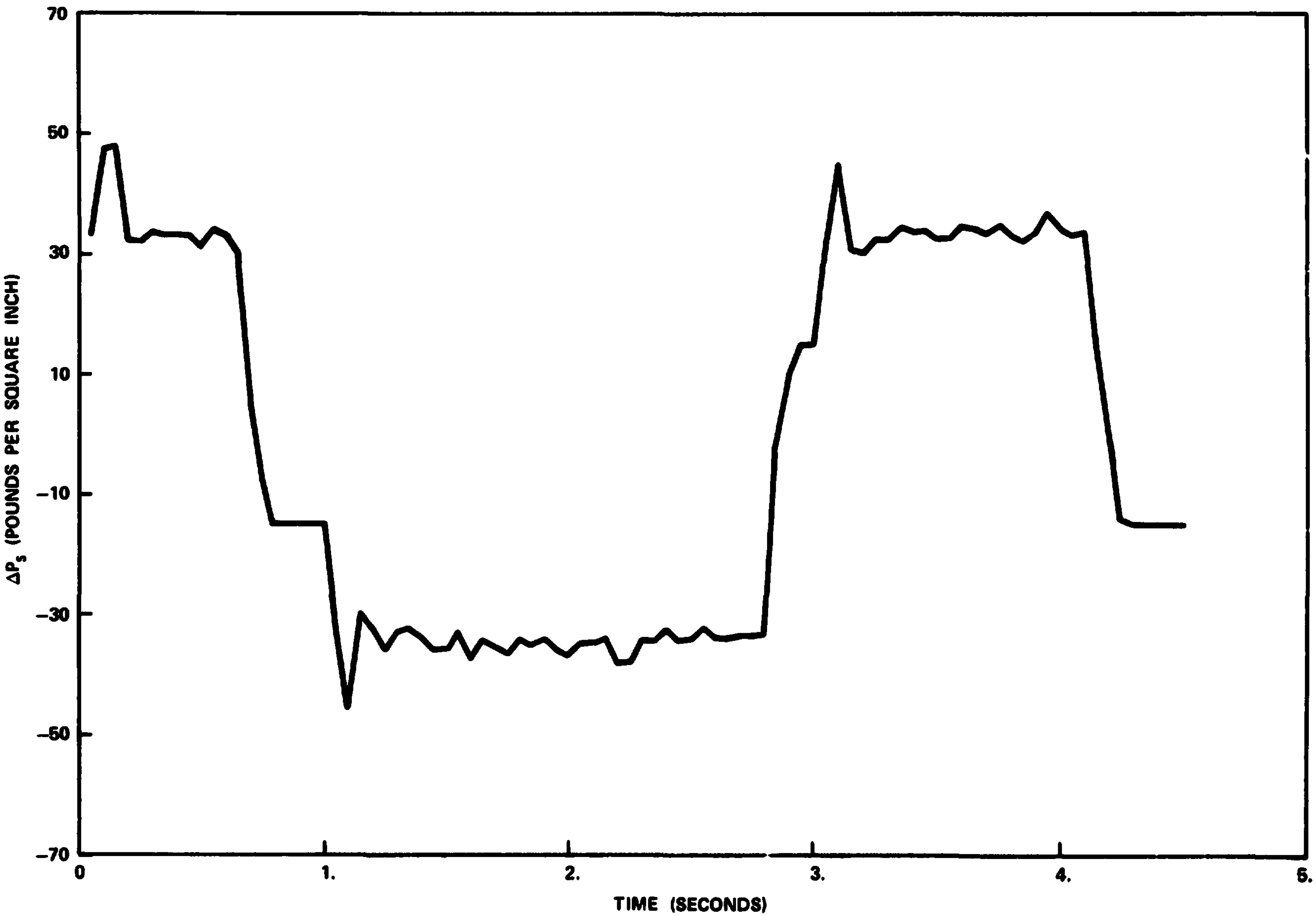
OUTBOARD ELEVON LARGE AMPLITUDE RESPONSE

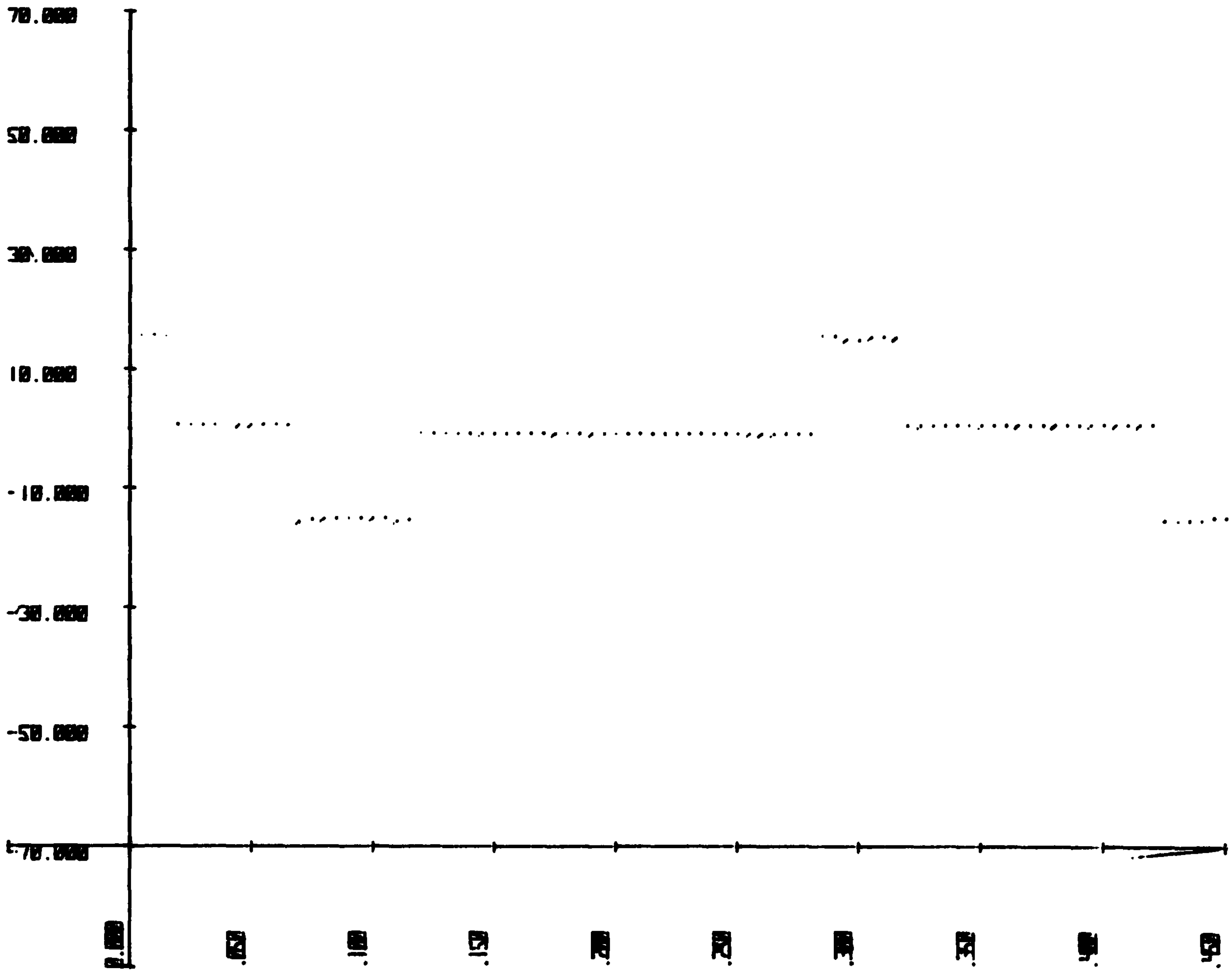


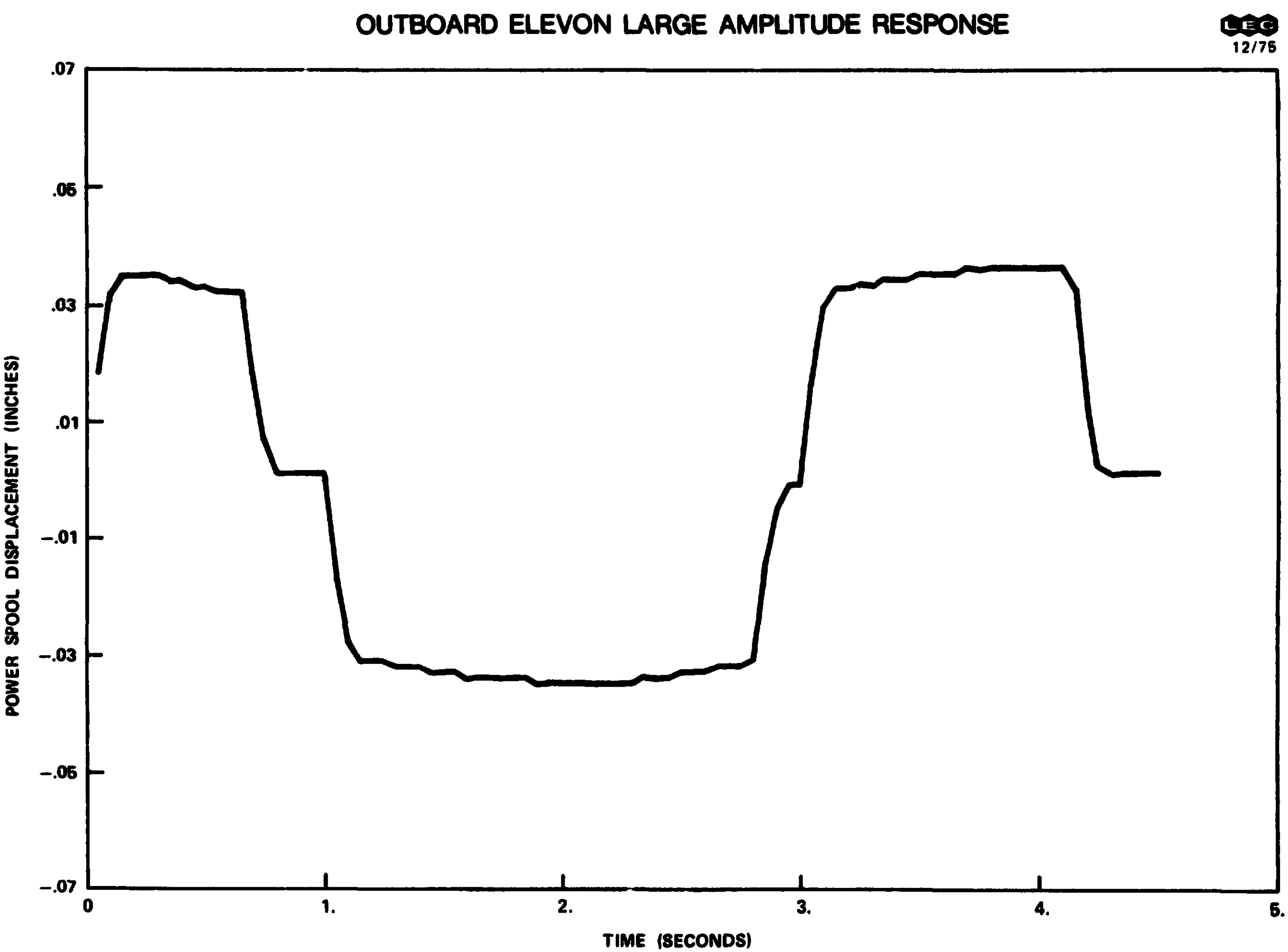

8.000
6.000
4.000
2.000
0.000
-2.000
-4.000
-6.000
0.000
.500
1.000
1.500
2.000
2.500
3.000
3.500
4.000
4.500

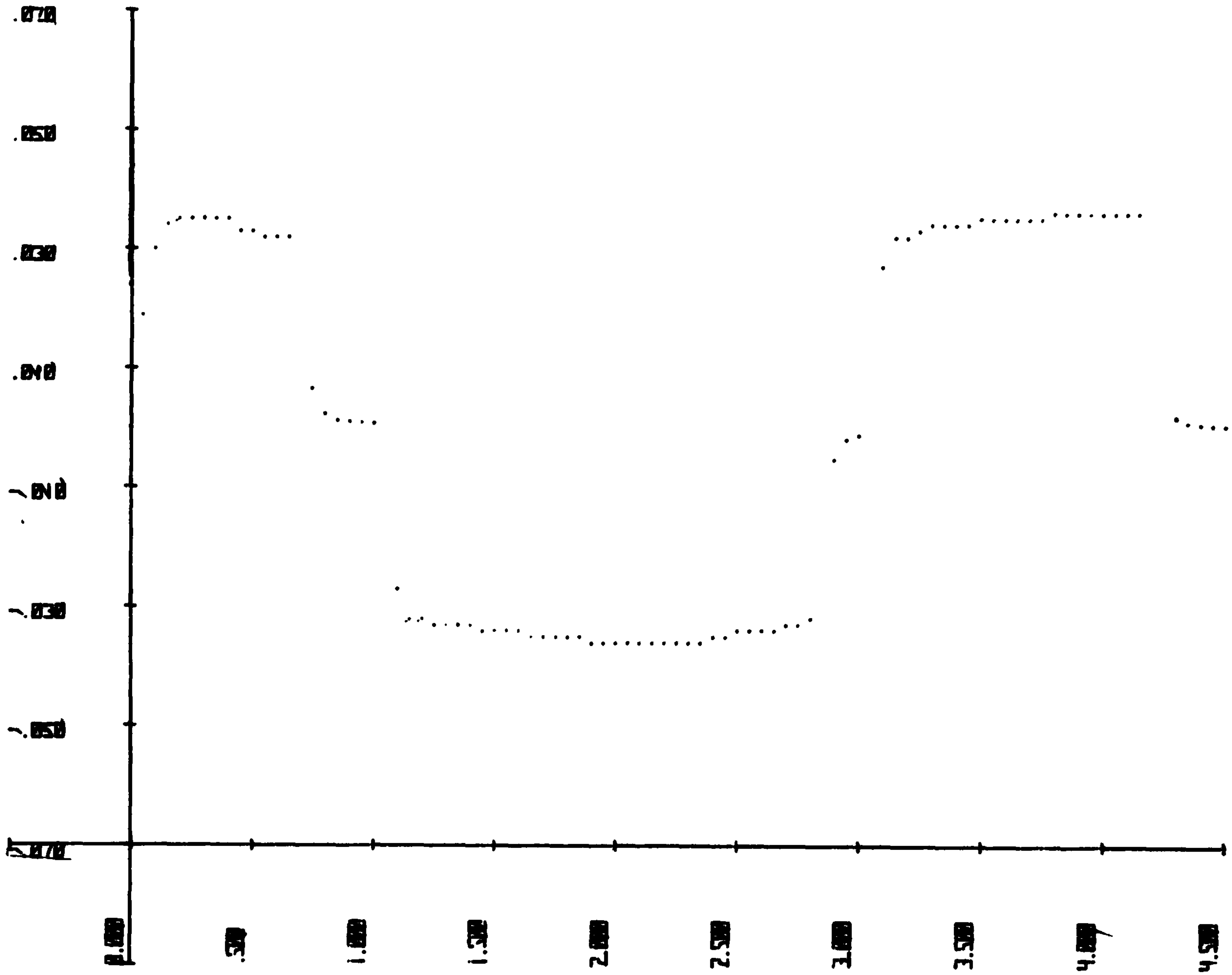
OUTBOARD ELEVON LARGE AMPLITUDE RESPONSE

12/75



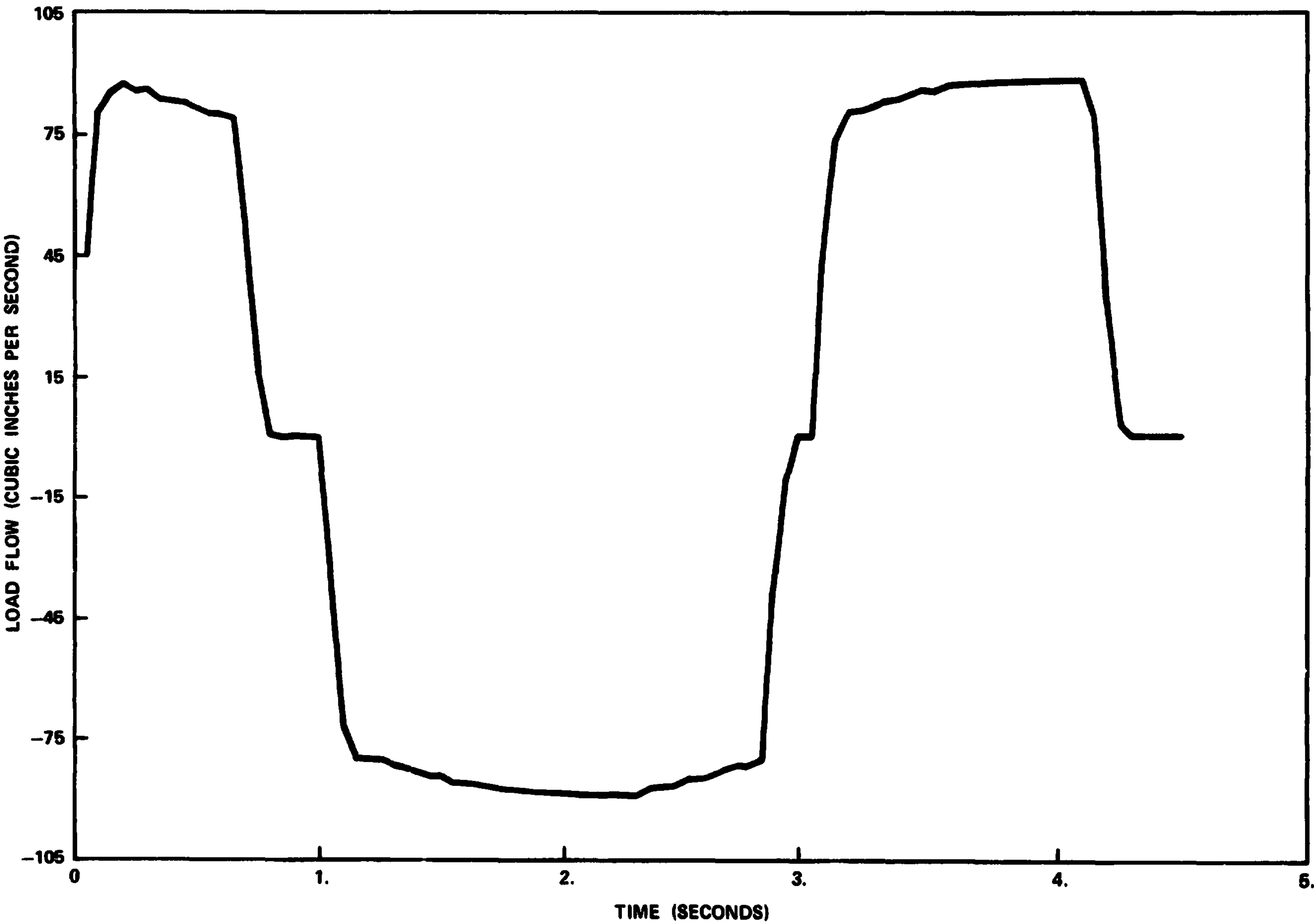

70.000
50.000
30.000
10.000
-10.000
-30.000
-50.000
-70.000

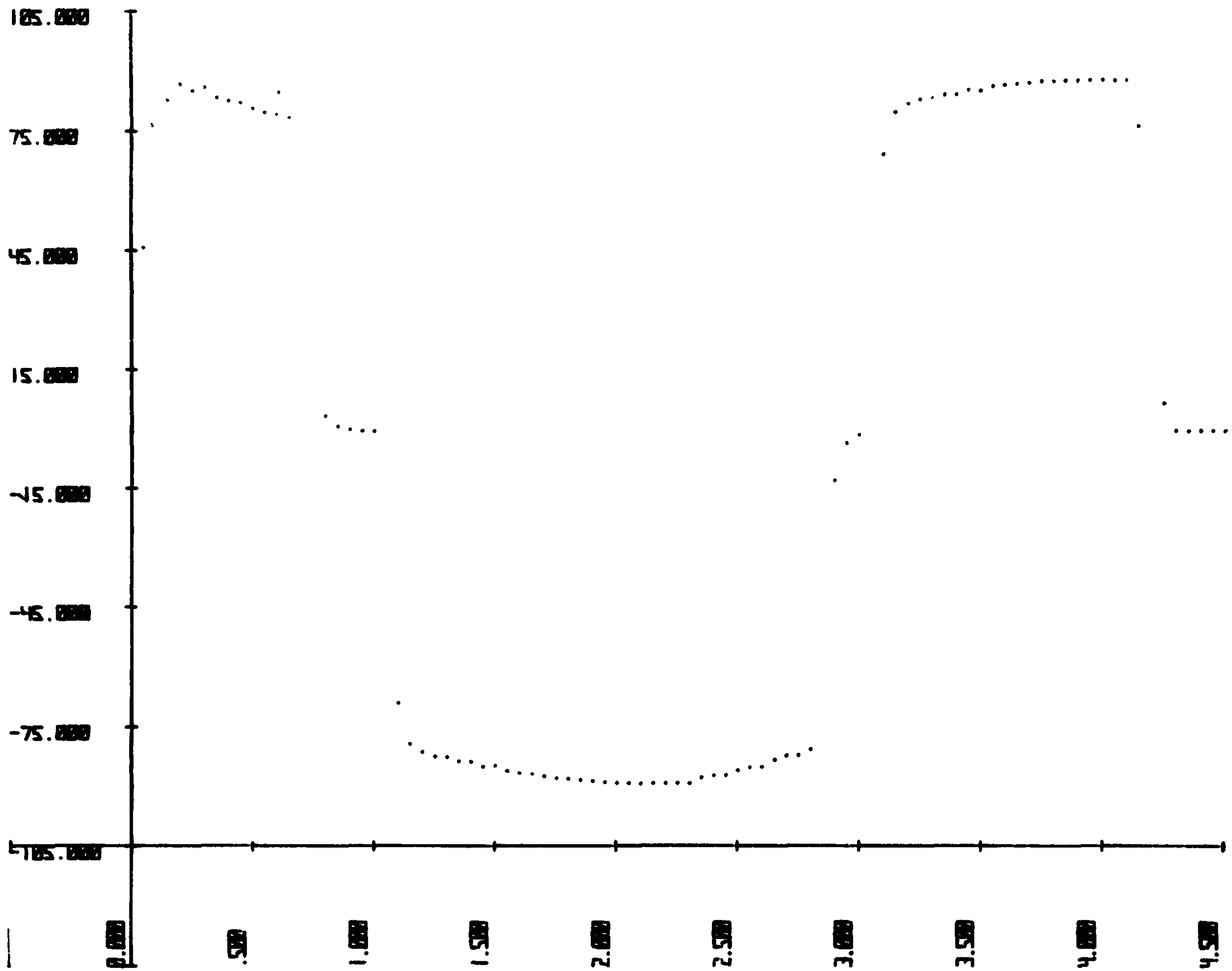

OUTBOARD ELEVON LARGE AMPLITUDE RESPONSE
12/75
.07
.05
.03
.01
-.01
-.03
-.05
-.07
POWER SPOOL DISPLACEMENT (INCHES)
0
1.
2.
3.
4.
5.
TIME (SECONDS)


.070
.050
.030
.010
-.010
-.030
-.050
-.070
0.000
.500
1.000
1.500
2.000
2.500
3.000
3.500
4.000
4.500

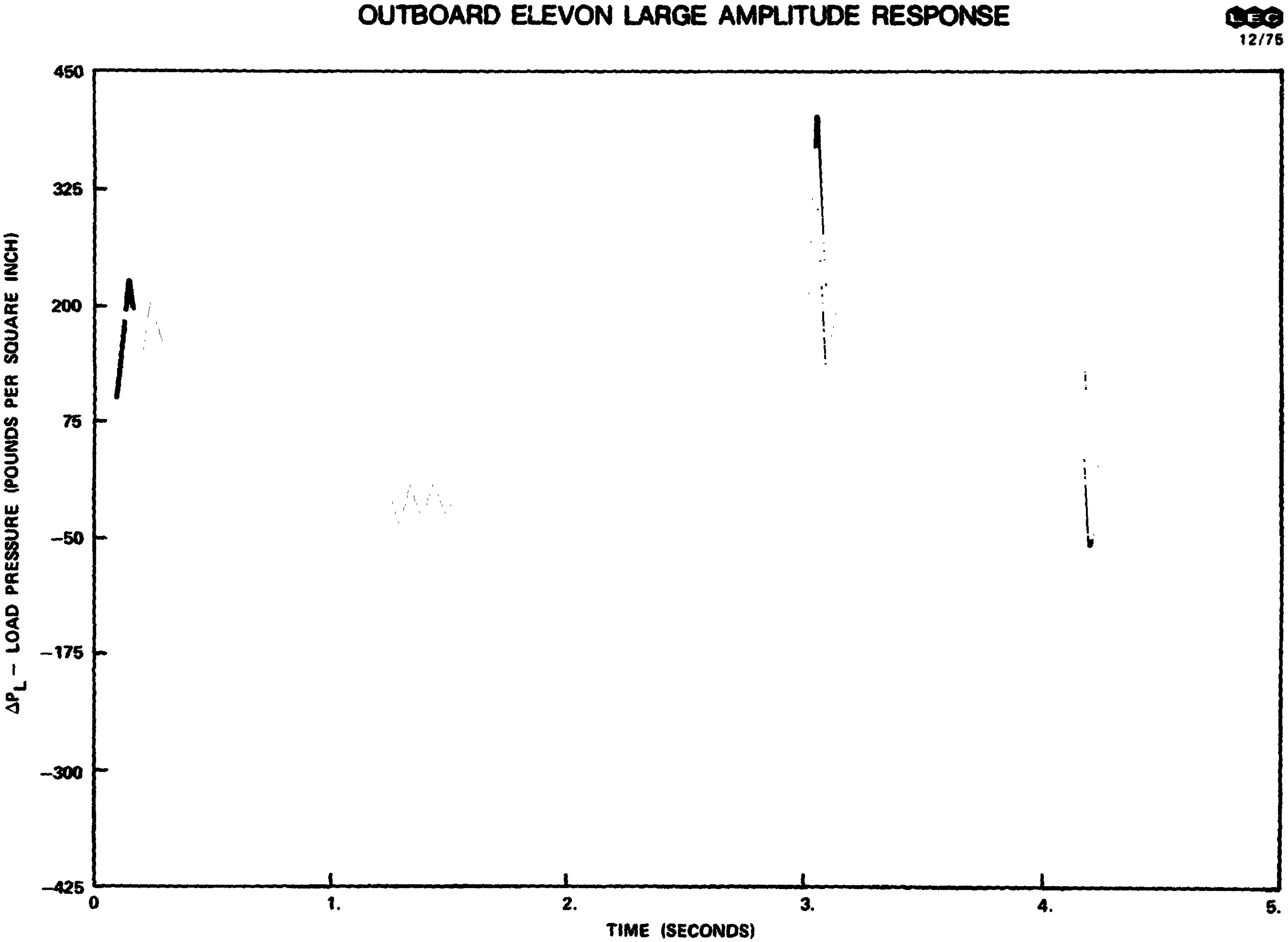
OUTBOARD ELEVON LARGE AMPLITUDE RESPONSE

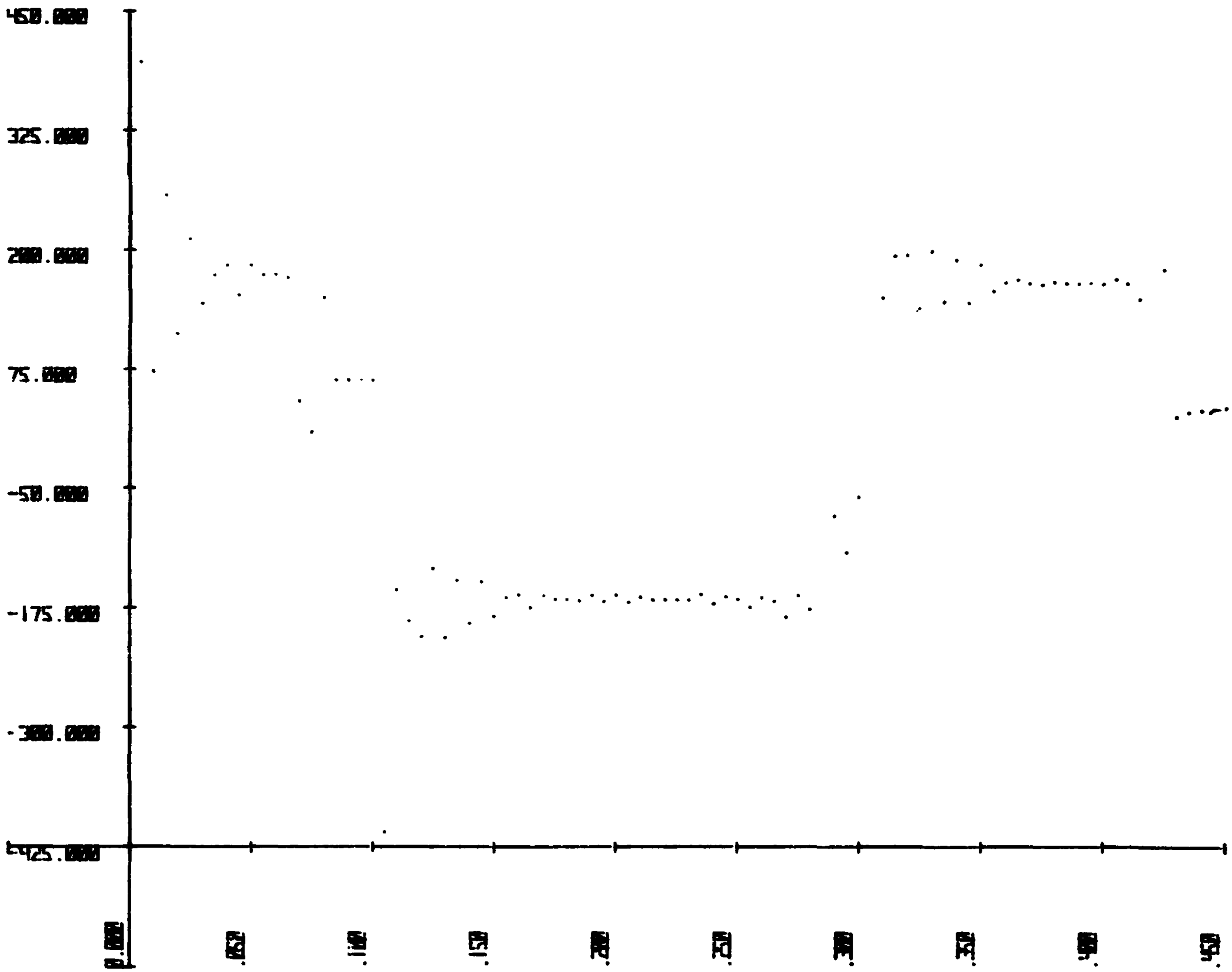
12/75




105.000
75.000
45.000
15.000
-15.000
-45.000
-75.000
-105.000
0.000
.500
1.000
1.500
2.000
2.500
3.000
3.500
4.000
4.500

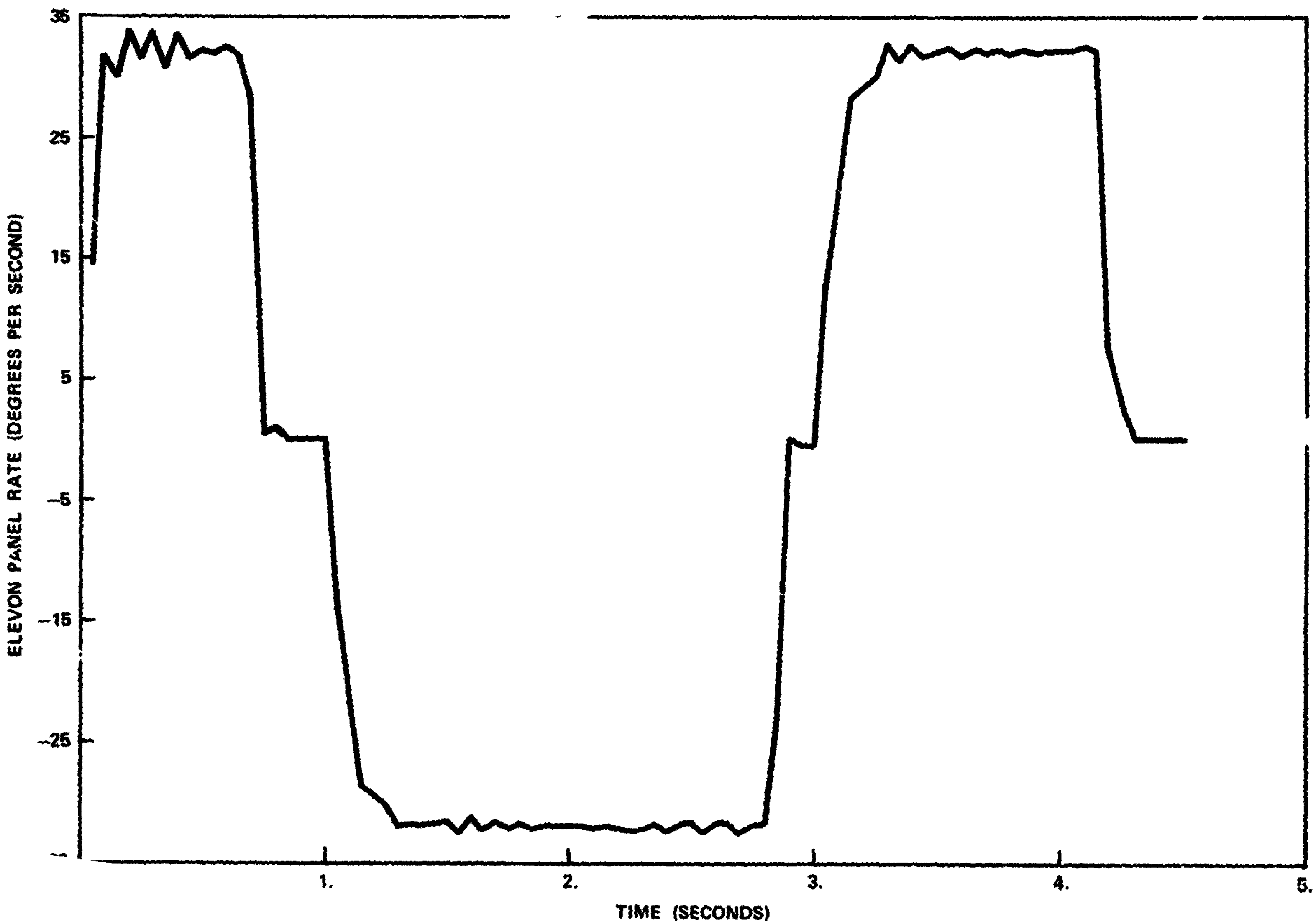
OUTBOARD ELEVON LARGE AMPLITUDE RESPONSE

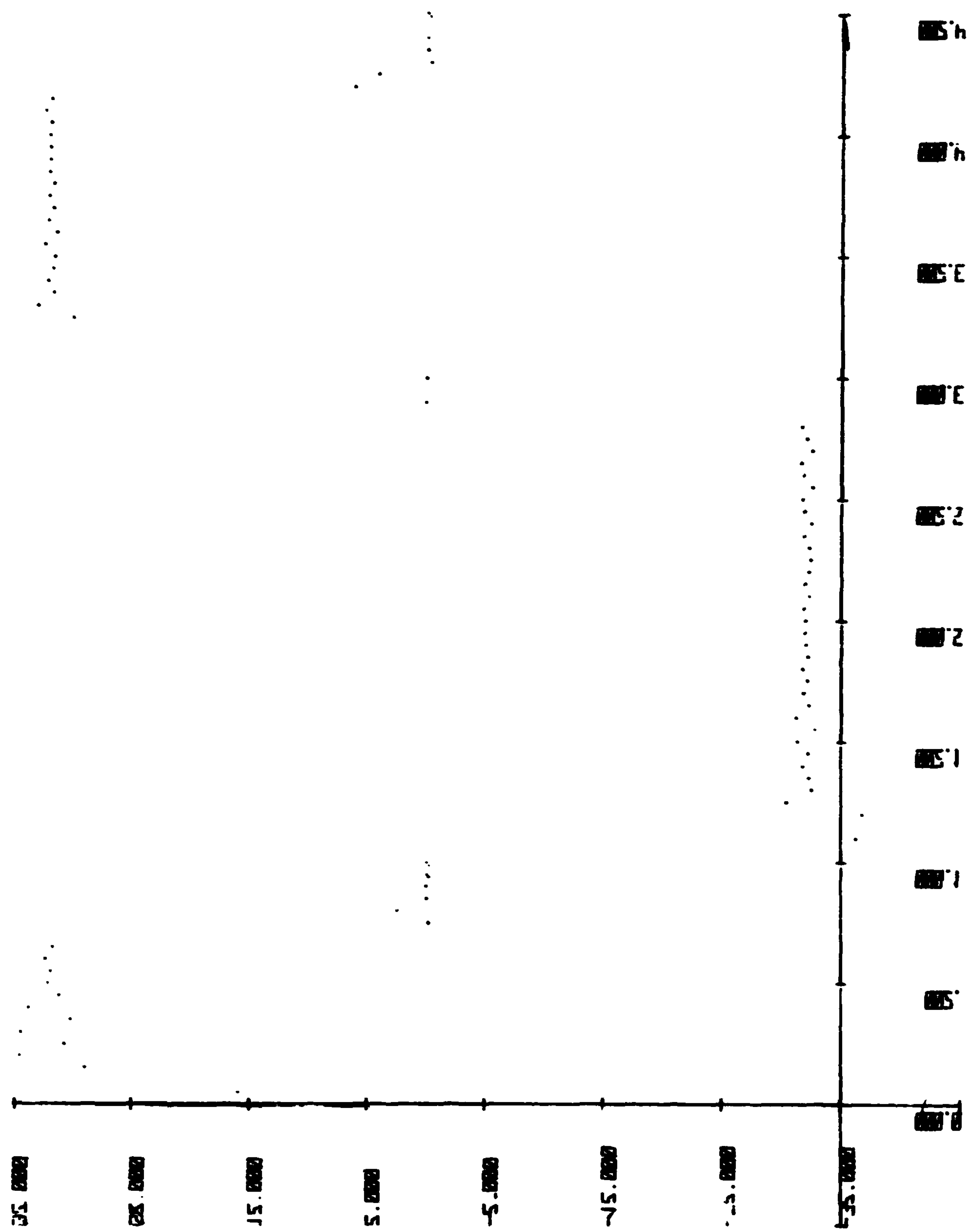



450.000
325.000
200.000
75.000
-50.000
-175.000
-300.000
-425.000

OUTBOARD ELEVON LARGE AMPLITUDE RESPONSE

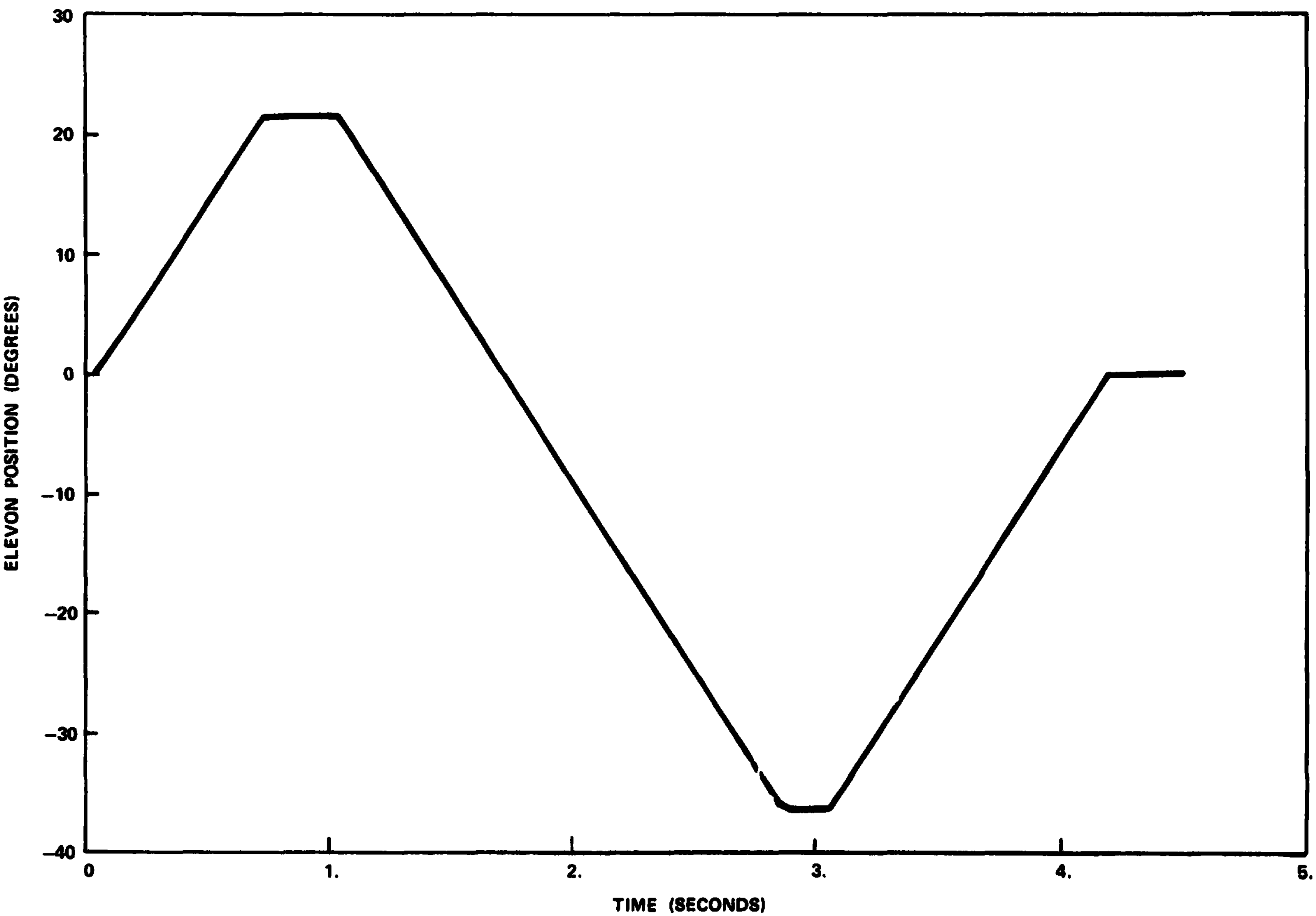
12/75

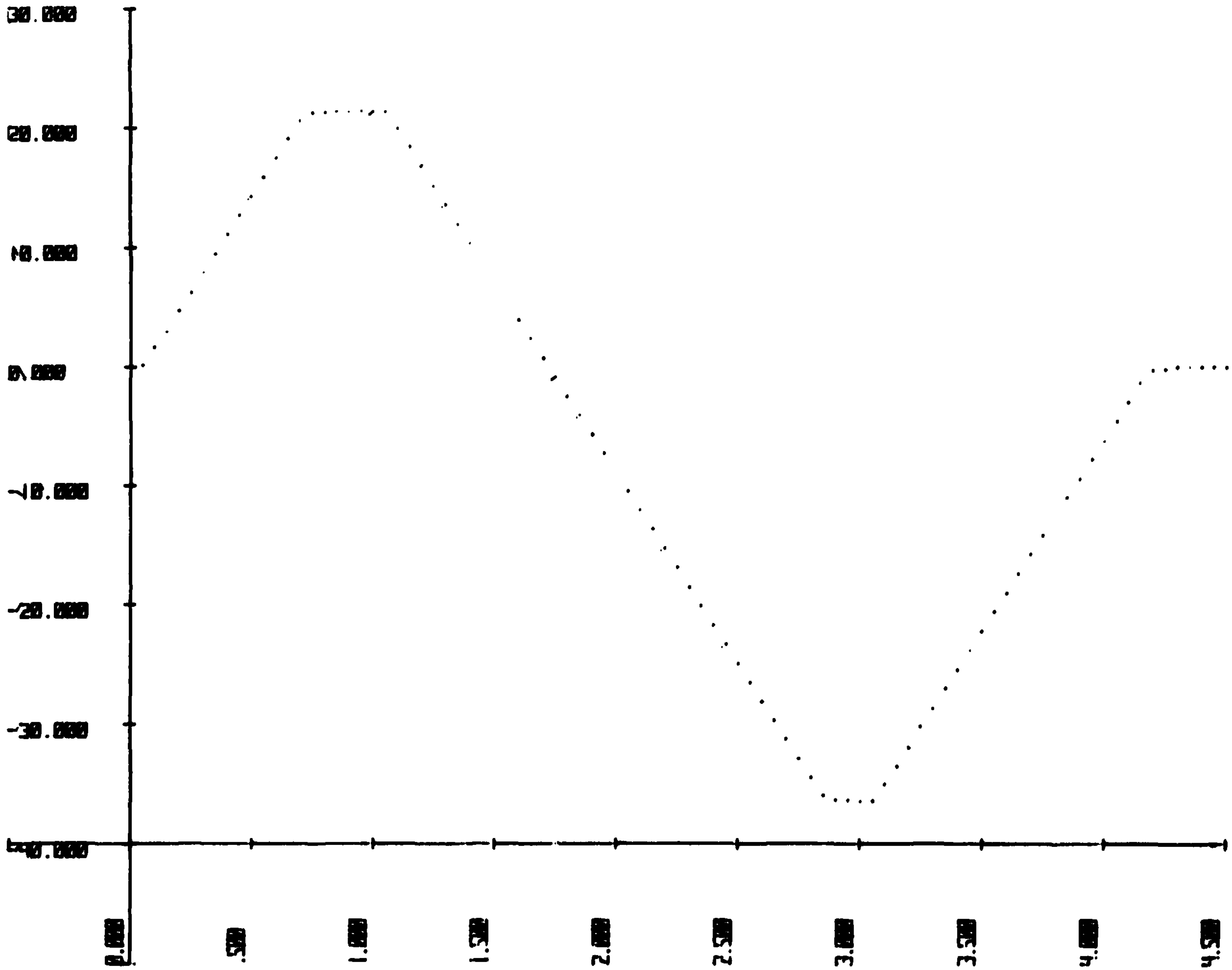




OUTBOARD ELEVON LARGE AMPLITUDE RESPONSE

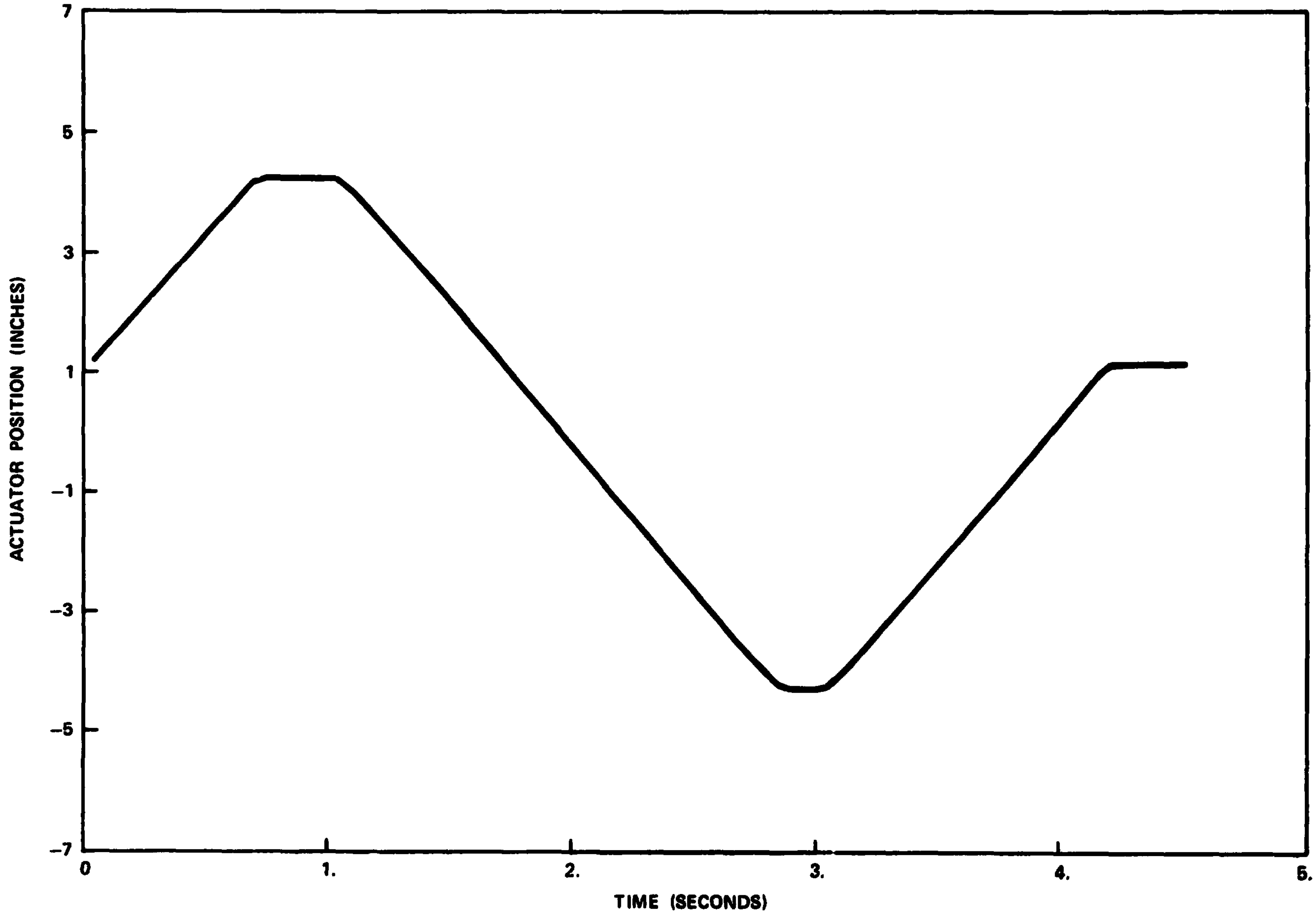
12/75

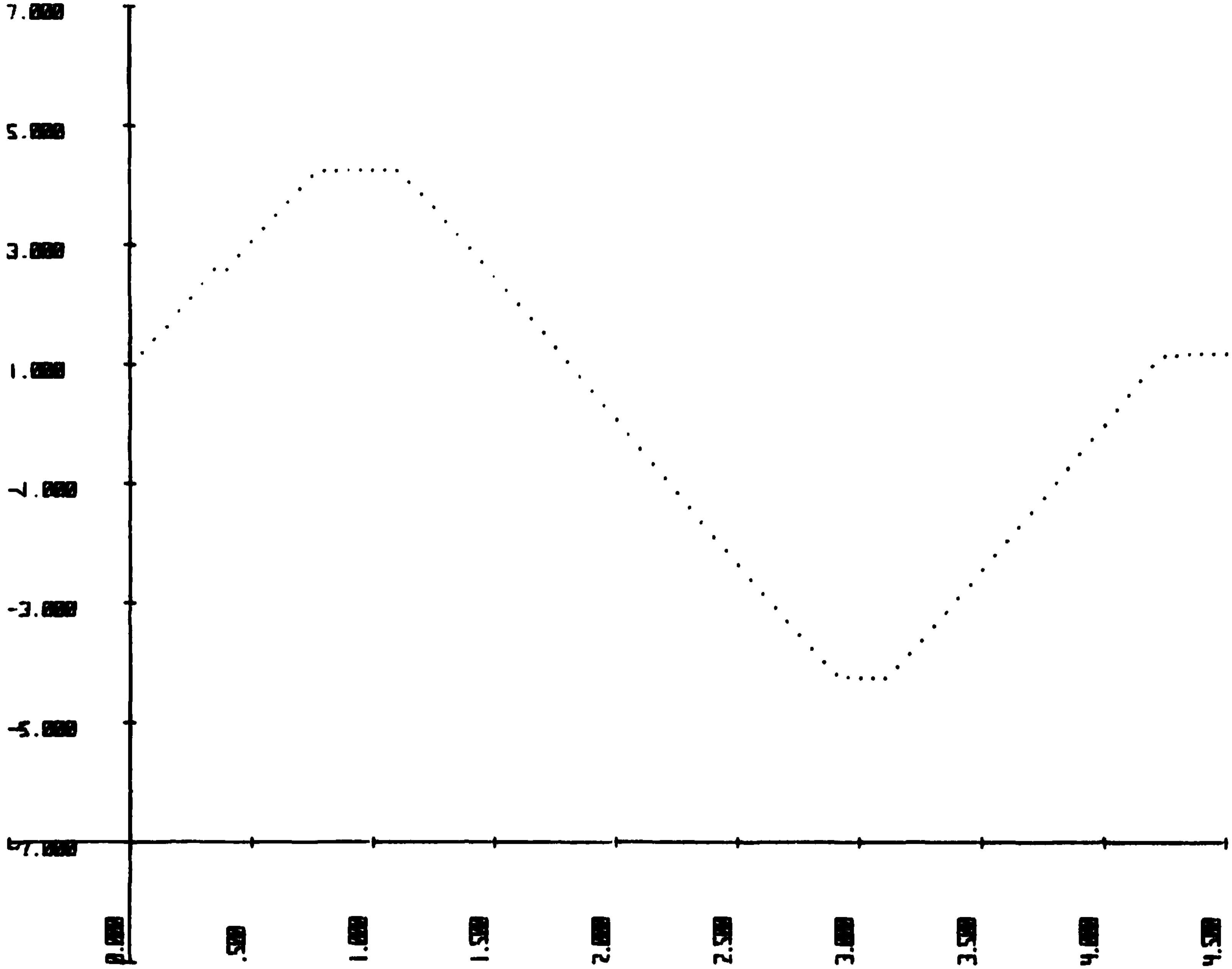


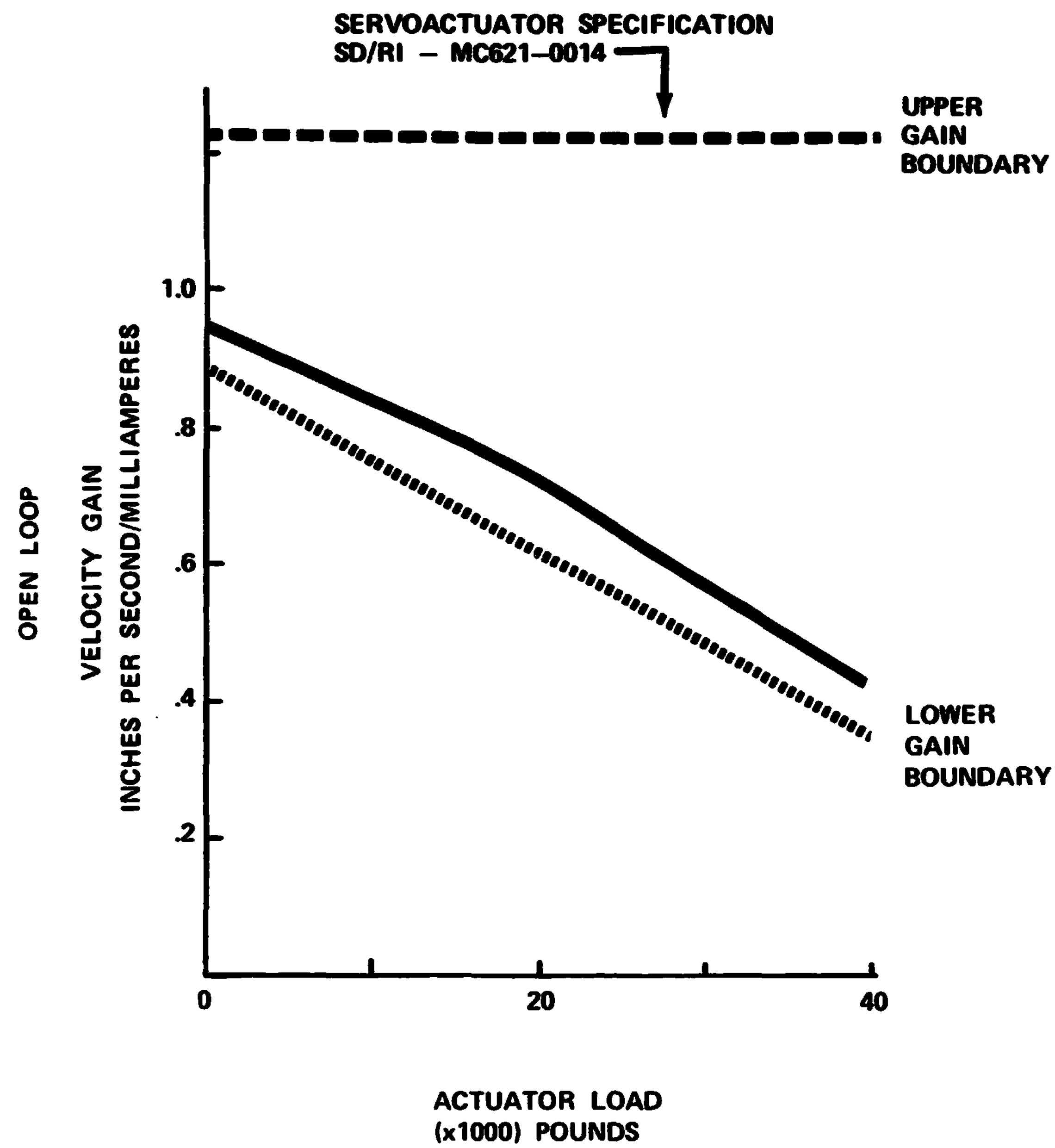

30.000
20.000
10.000
0.000
-10.000
-20.000
-30.000
-40.000

OUTBOARD ELEVON LARGE AMPLITUDE RESPONSE

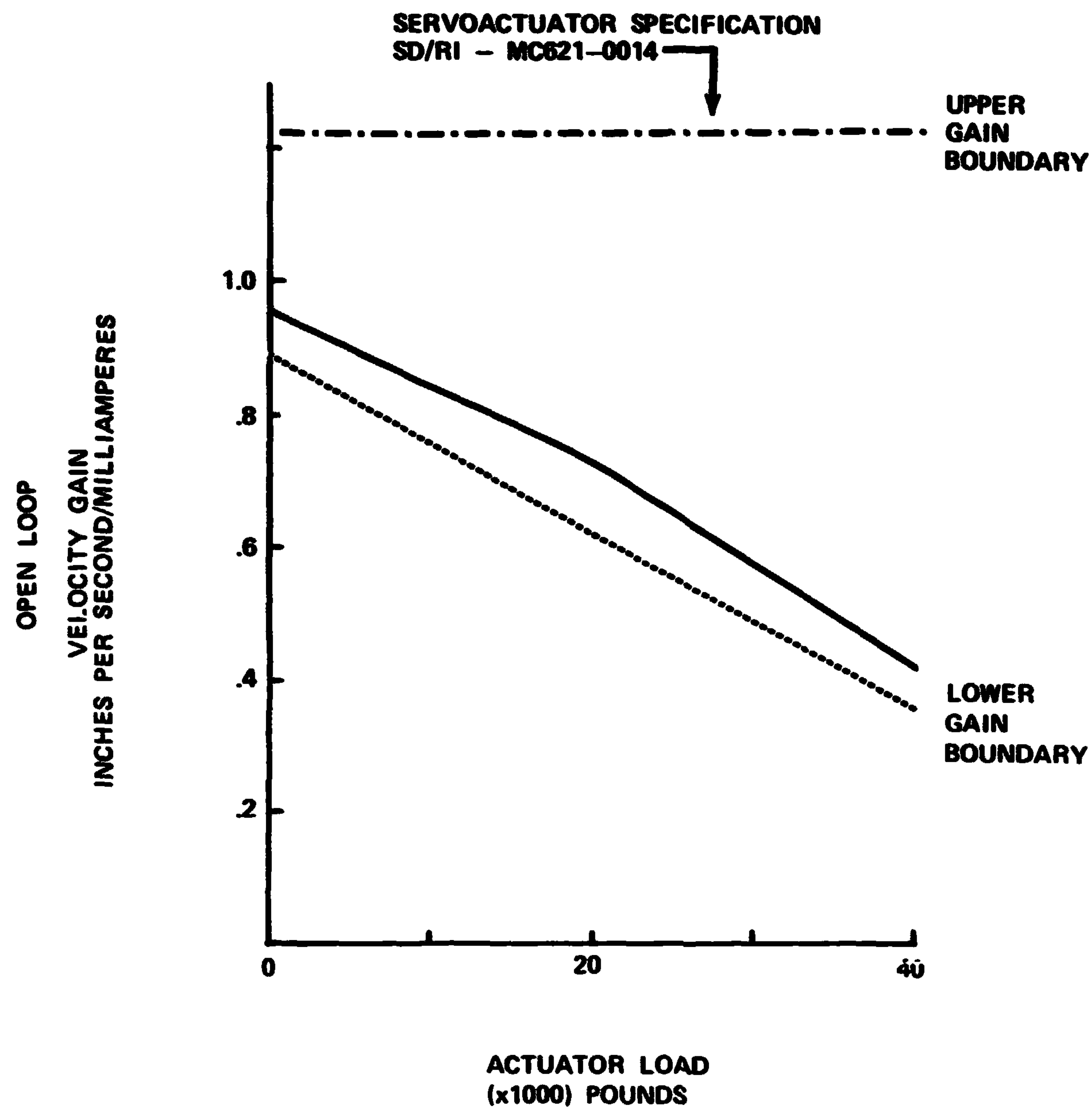
12/76



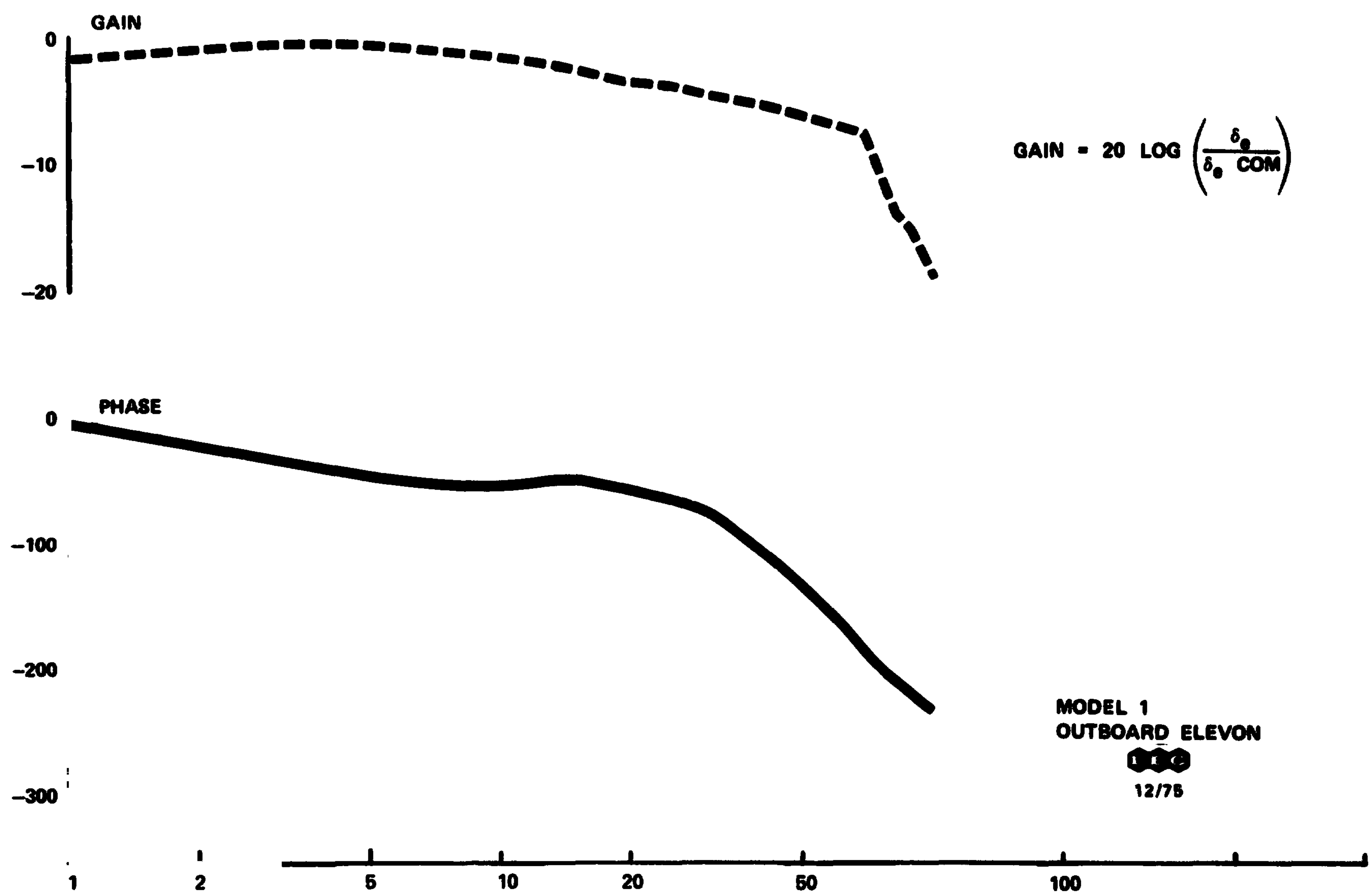

7.000
5.000
3.000
1.000
-1.000
-3.000
-5.000
-7.000

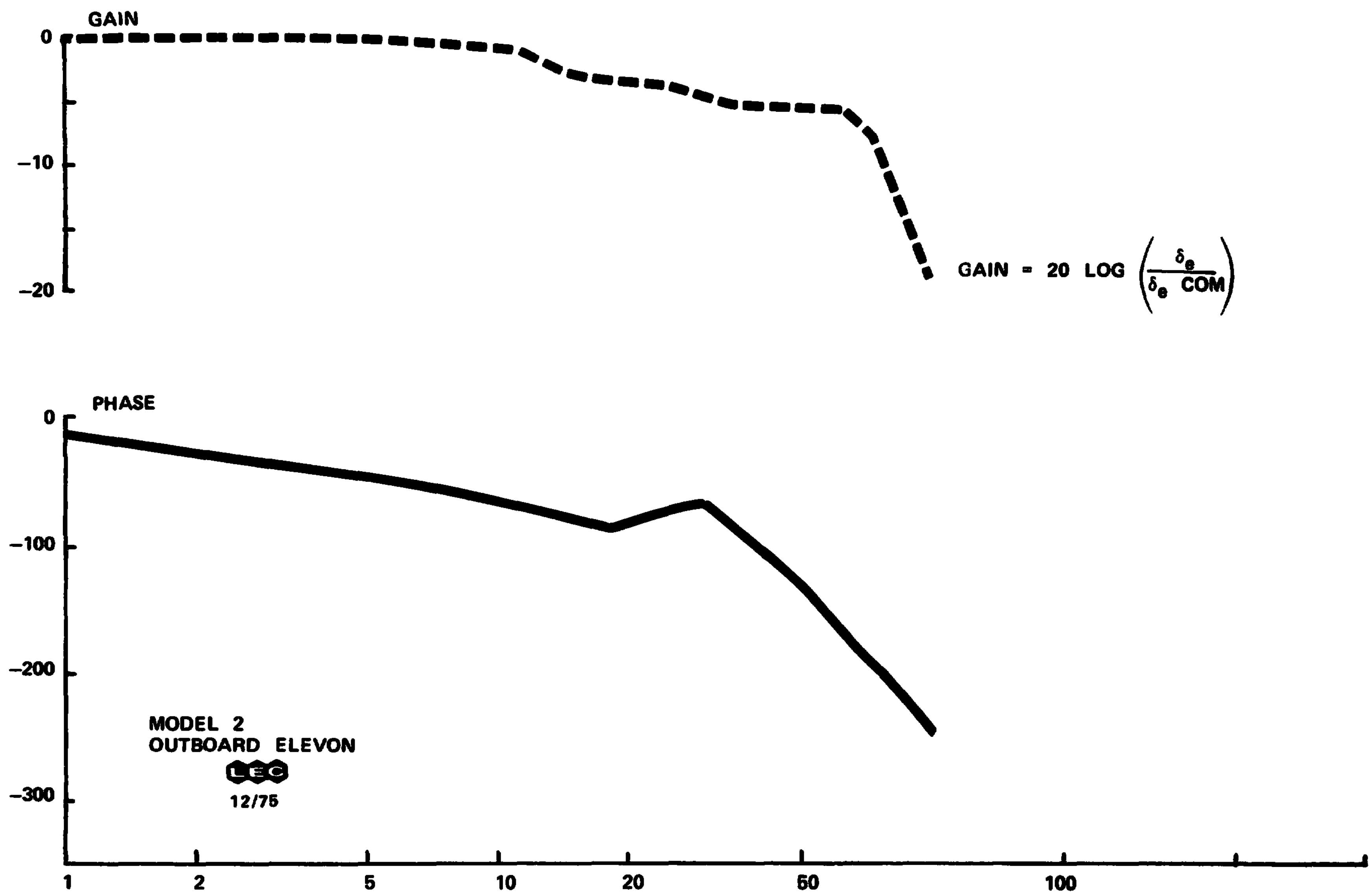


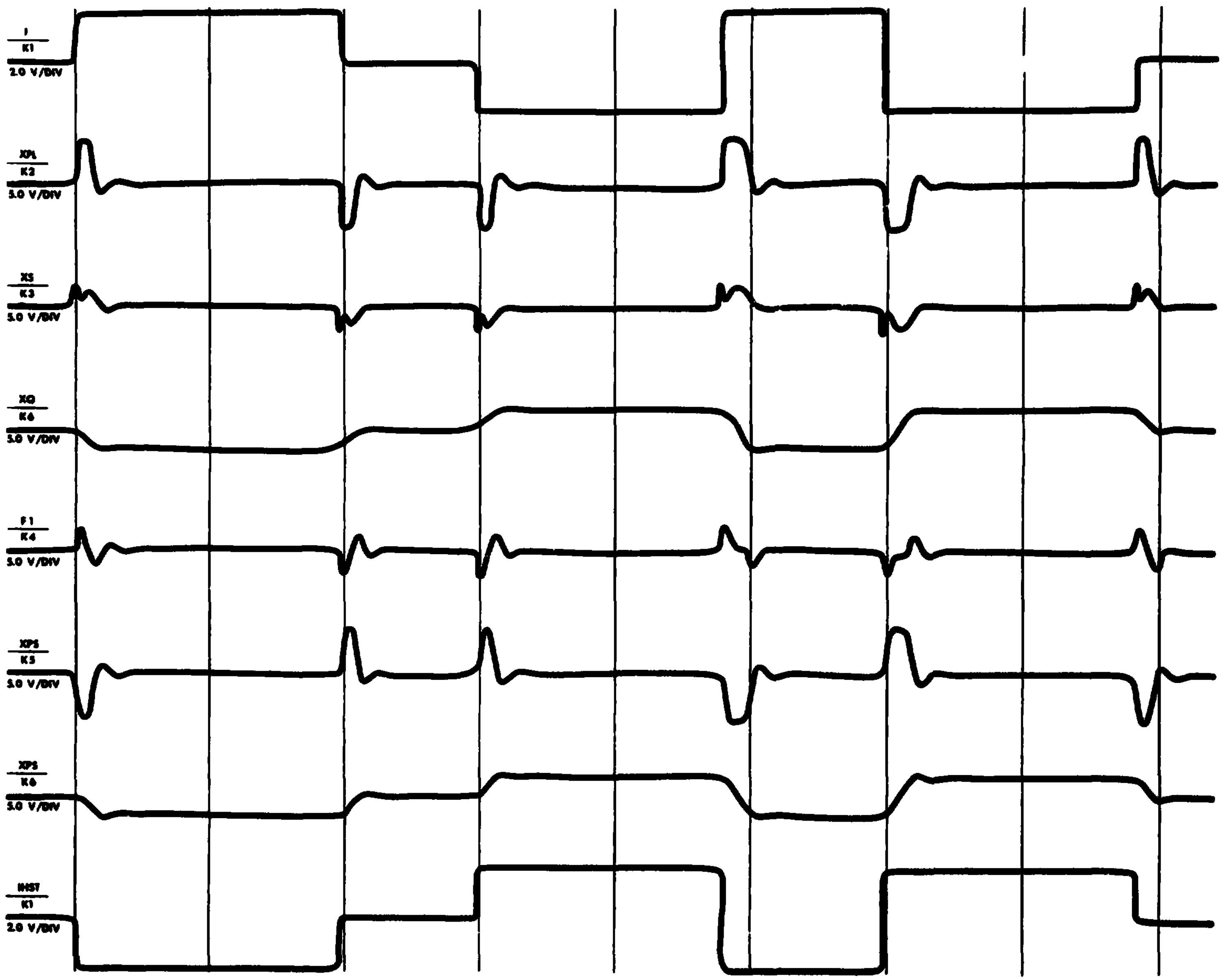
MODEL 1
OUTBOARD ELEVON
LEC
12/75



MODEL 2
OUTBOARD ELEVON
12/75

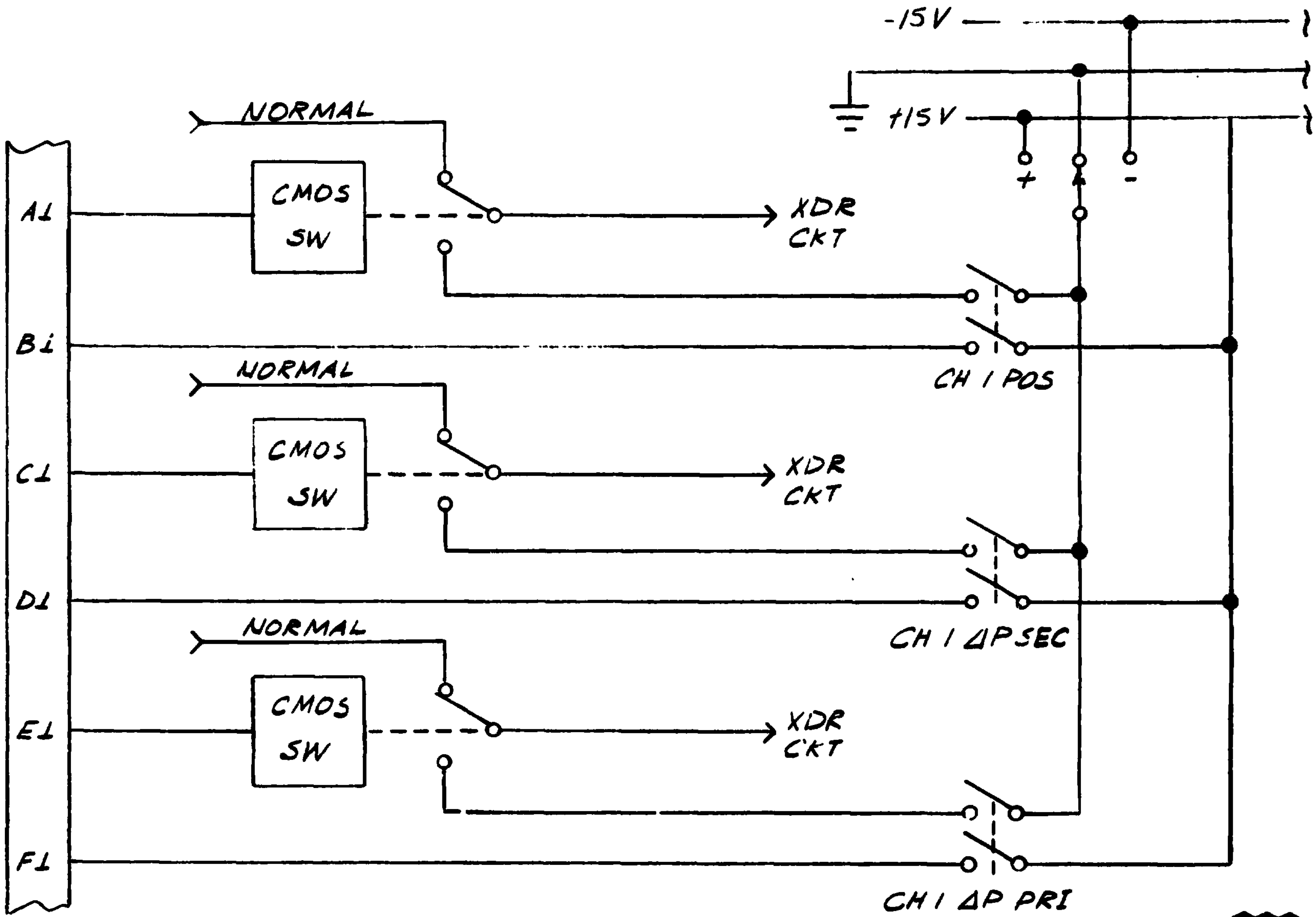

GAIN
0
-10
-20
GAIN = 20 LOG $\left(\frac{\delta_e}{\delta_e \text{ COM}}\right)$
PHASE
0
-100
-200
-300
1
2
5
10
20
50
100
MODEL 1
OUTBOARD ELEVON
12/75


GAIN
0
-10
-20
GAIN = 20 LOG $\left(\frac{\delta_e}{\delta_e \text{ COM}}\right)$
PHASE
0
-100
-200
-300
MODEL 2
OUTBOARD ELEVON
LEC
12/75
1
2
5
10
20
50
100



I / K1
2.0 V/DIV
XPL / K2
5.0 V/DIV
XS / K3
5.0 V/DIV
XO / K6
5.0 V/DIV
F1 / K4
5.0 V/DIV
XPS / K5
5.0 V/DIV
XPS / K6
5.0 V/DIV
IHST / K1
2.0 V/DIV

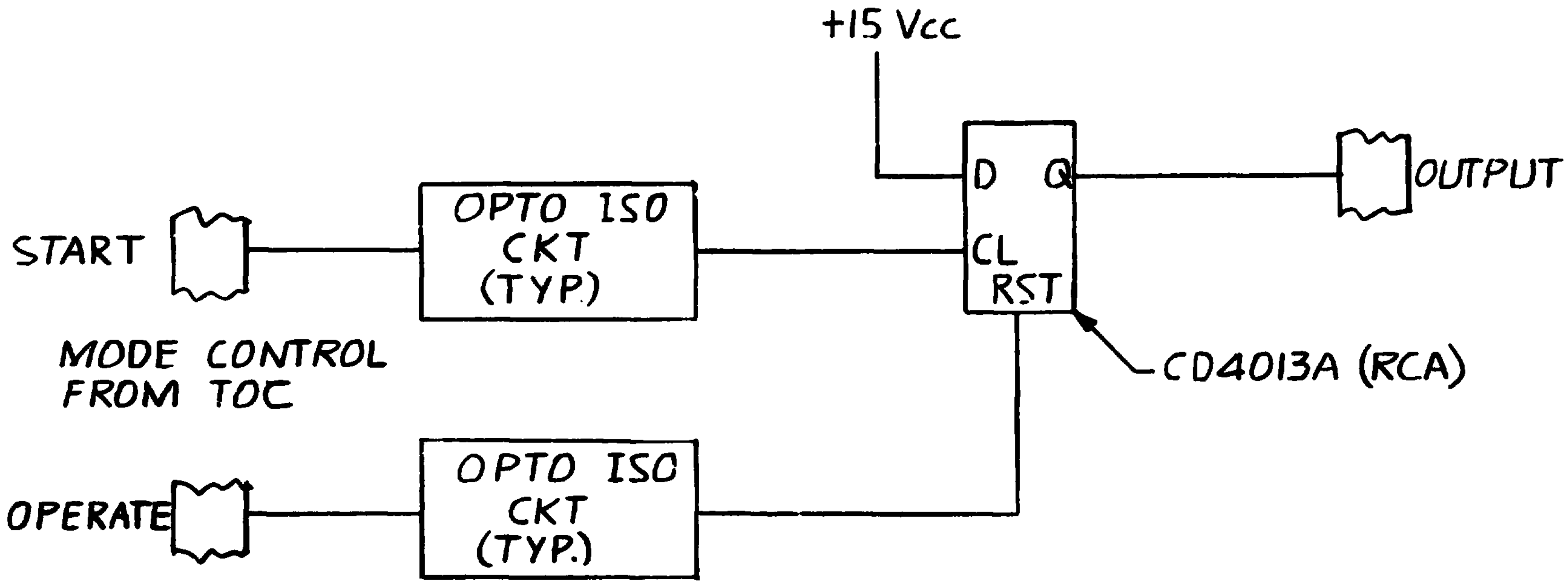
RUN ON CI-175



SAS/TOC INTERFACE

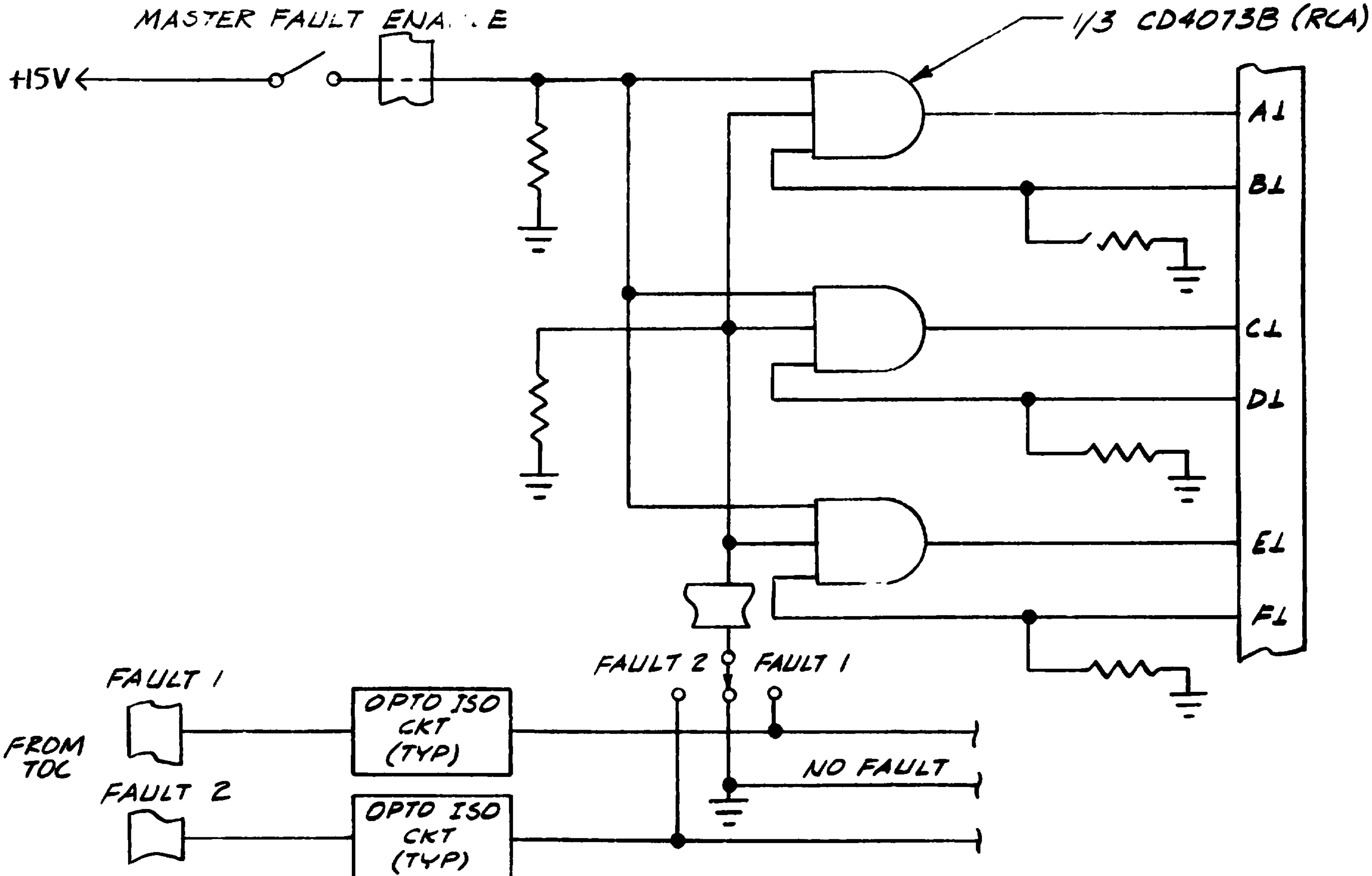
FAULT INSERTION SWITCHING CIRCUIT (TYP) PART B

LEC/HH
12-3-75



MODE CONTROL CIRCUIT (TYPICAL)

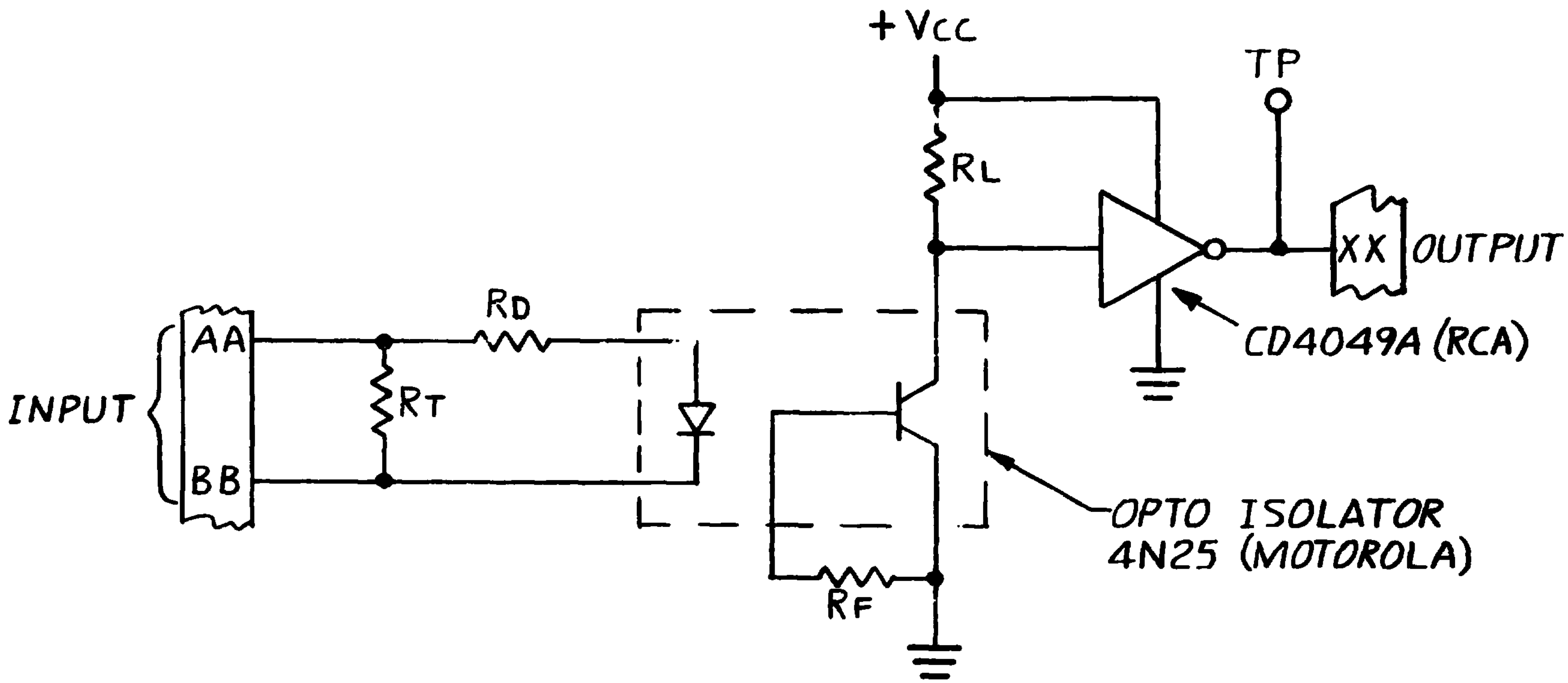
LEC/HH
12-3-75



SAS/TOC INTERFACE

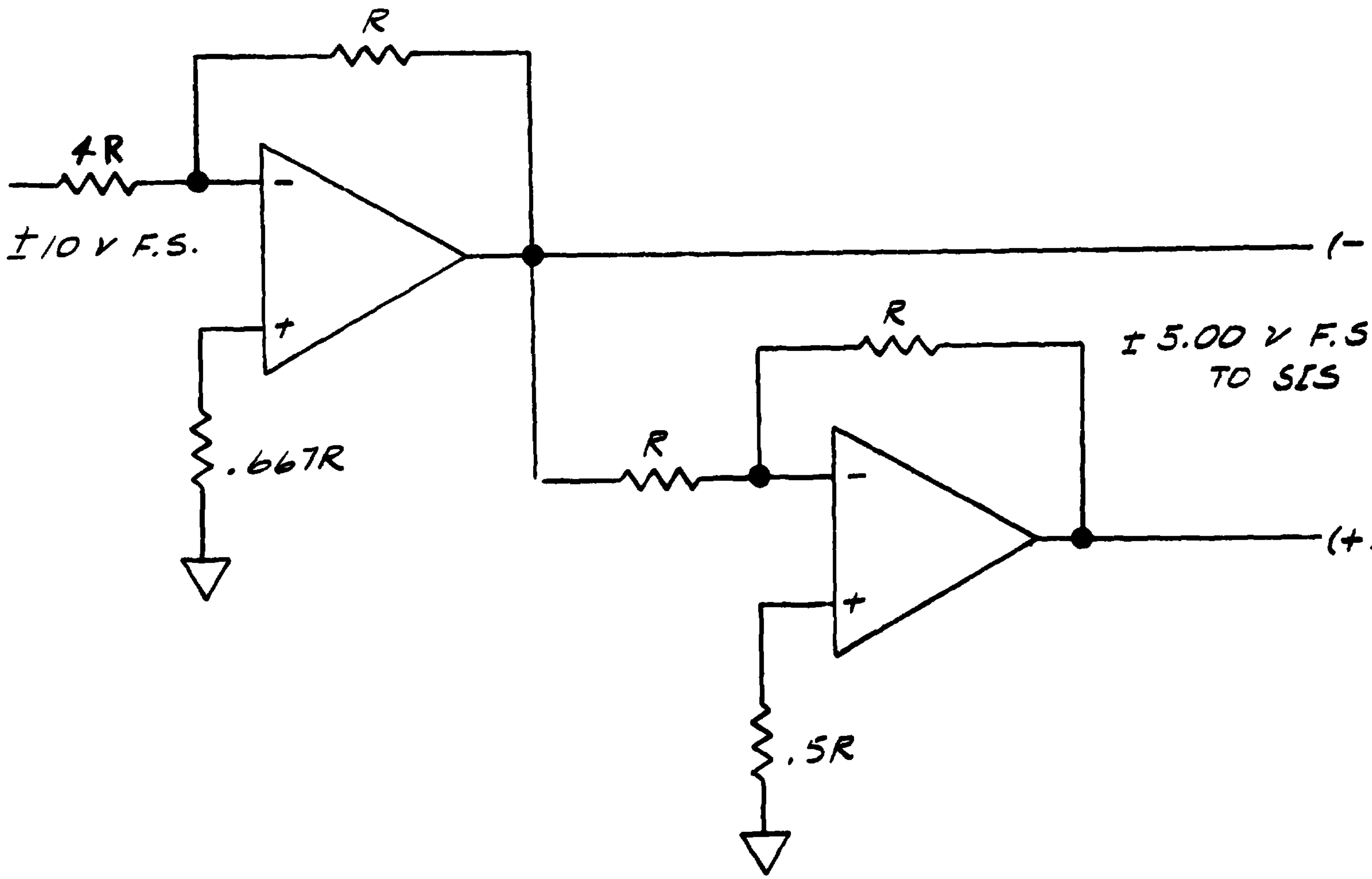
FAULT INSERTION SWITCHING CIRCUIT (TYP) PART A

LEC/HH
12·3·75



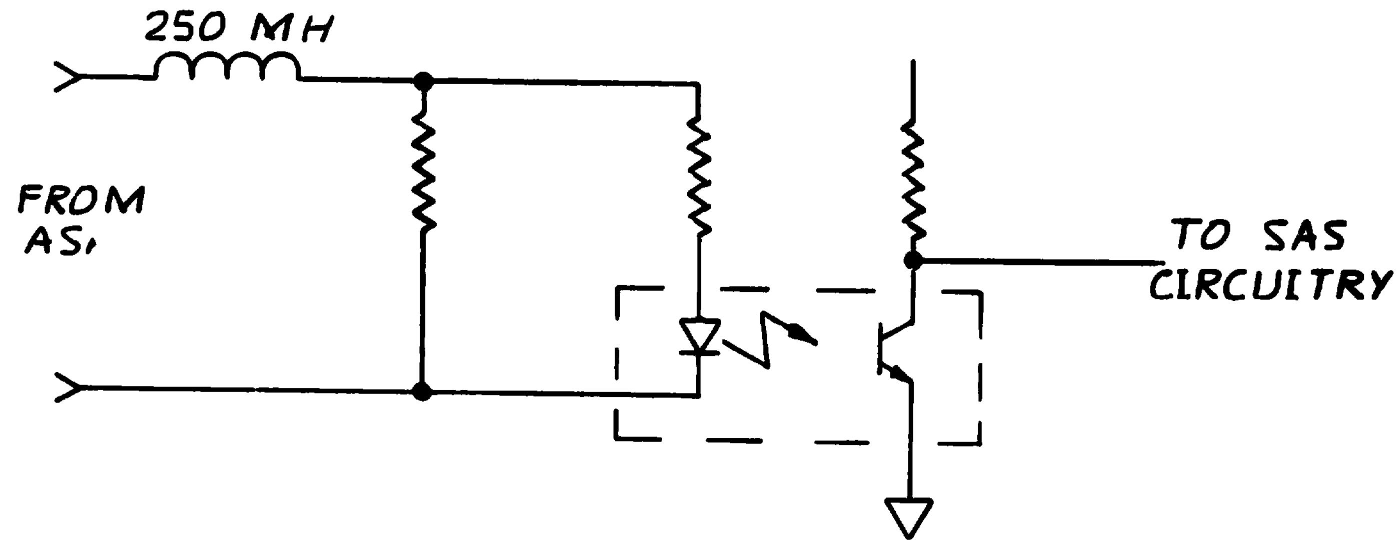
OPTO-ISOLATOR CIRCUIT (TYPICAL)
MODE/FAULT INSERTION

LEC/HH
12-3-75



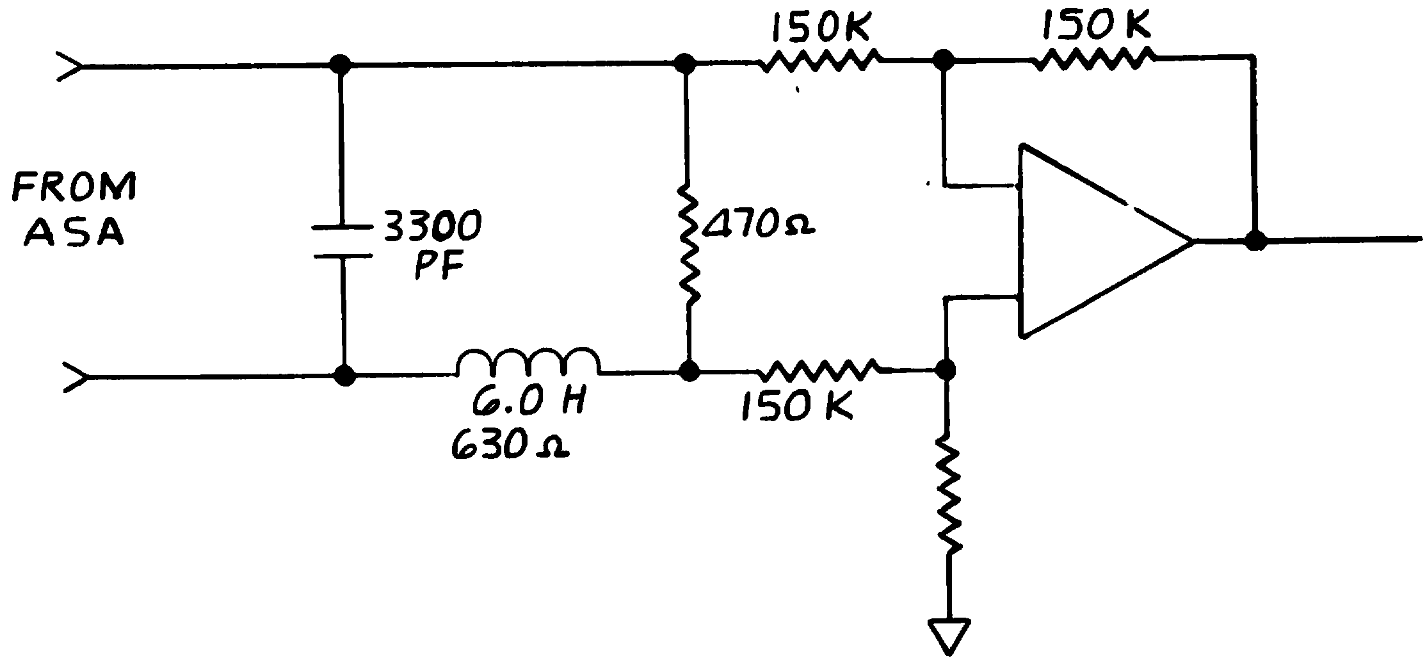
POSITION/ACCELLERATION SAS/SIS INTERFACE

LEC/CLF
12/2/75



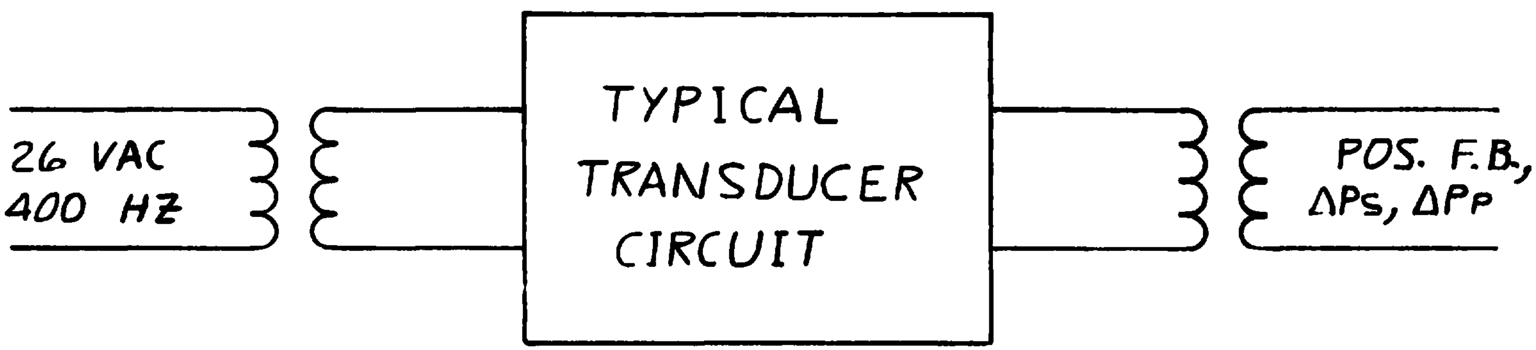
ELEVON ISOLATION VALVE
ASA/SAS INTERFACE

LEC/CLF
12-2-75



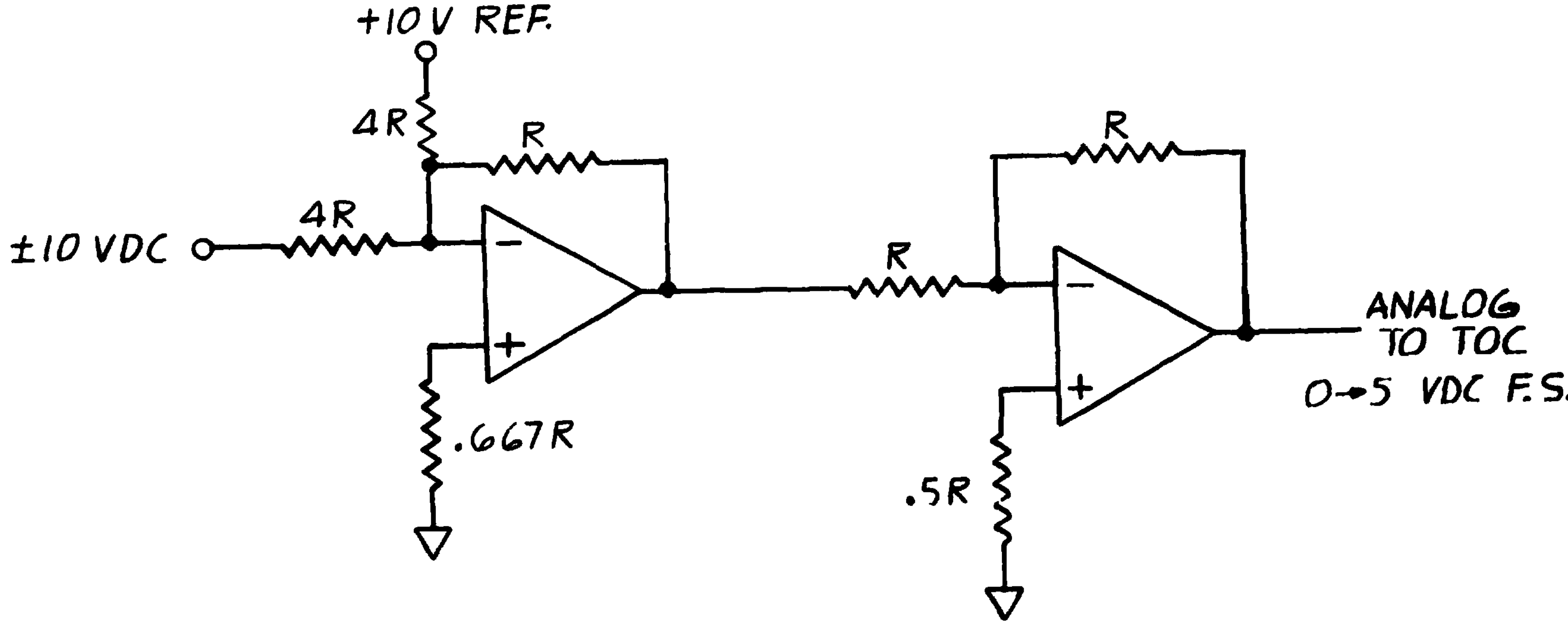
ELEVON SERVO VALVE
ASA/SAS INTERFACE

LEC/CLF
12-2-75



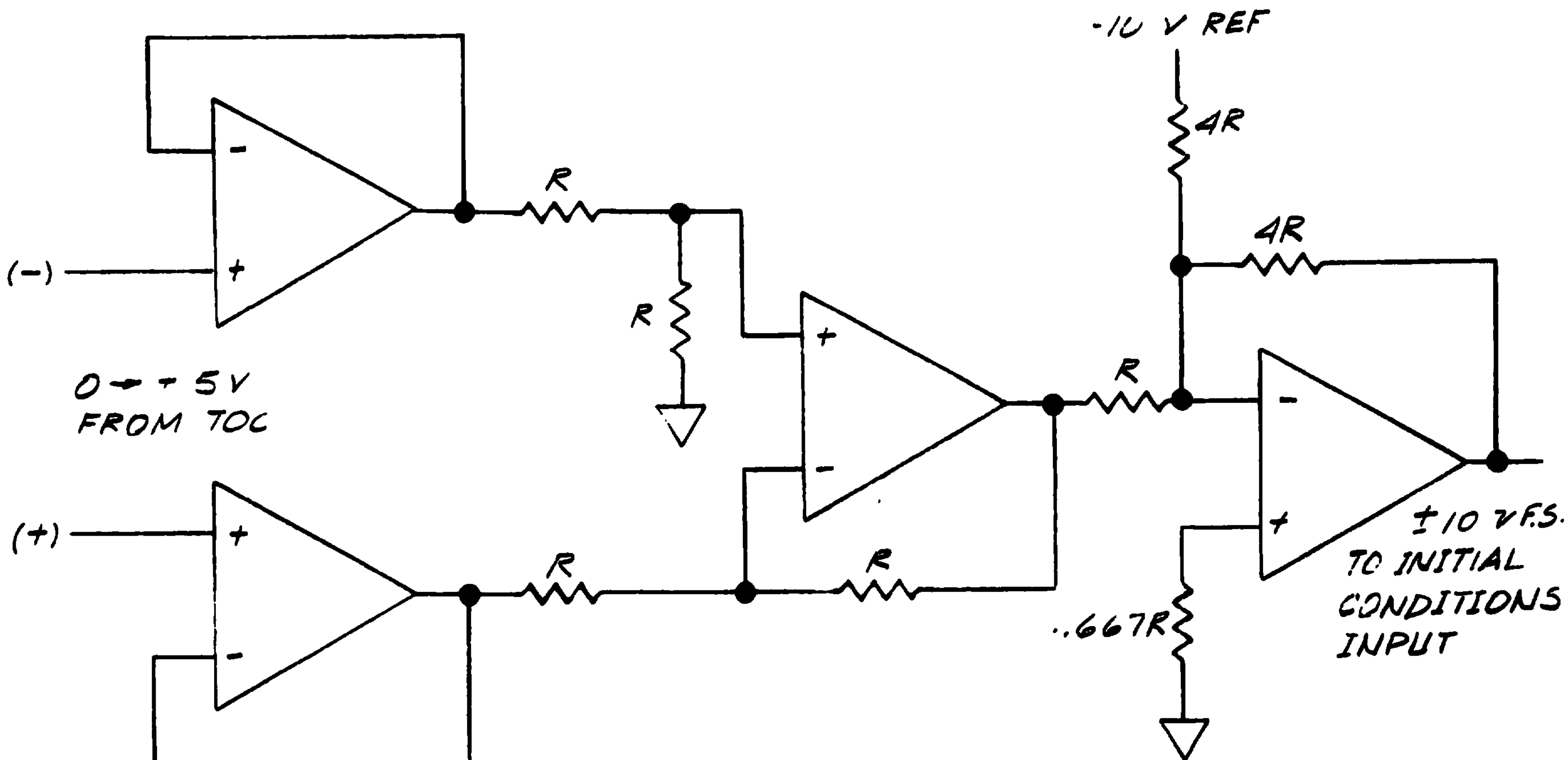
TYPICAL TRANSFORMER COUPLED
ISOLATION CIRCUIT ASA/SAS

LEC/CLF
12-2-75



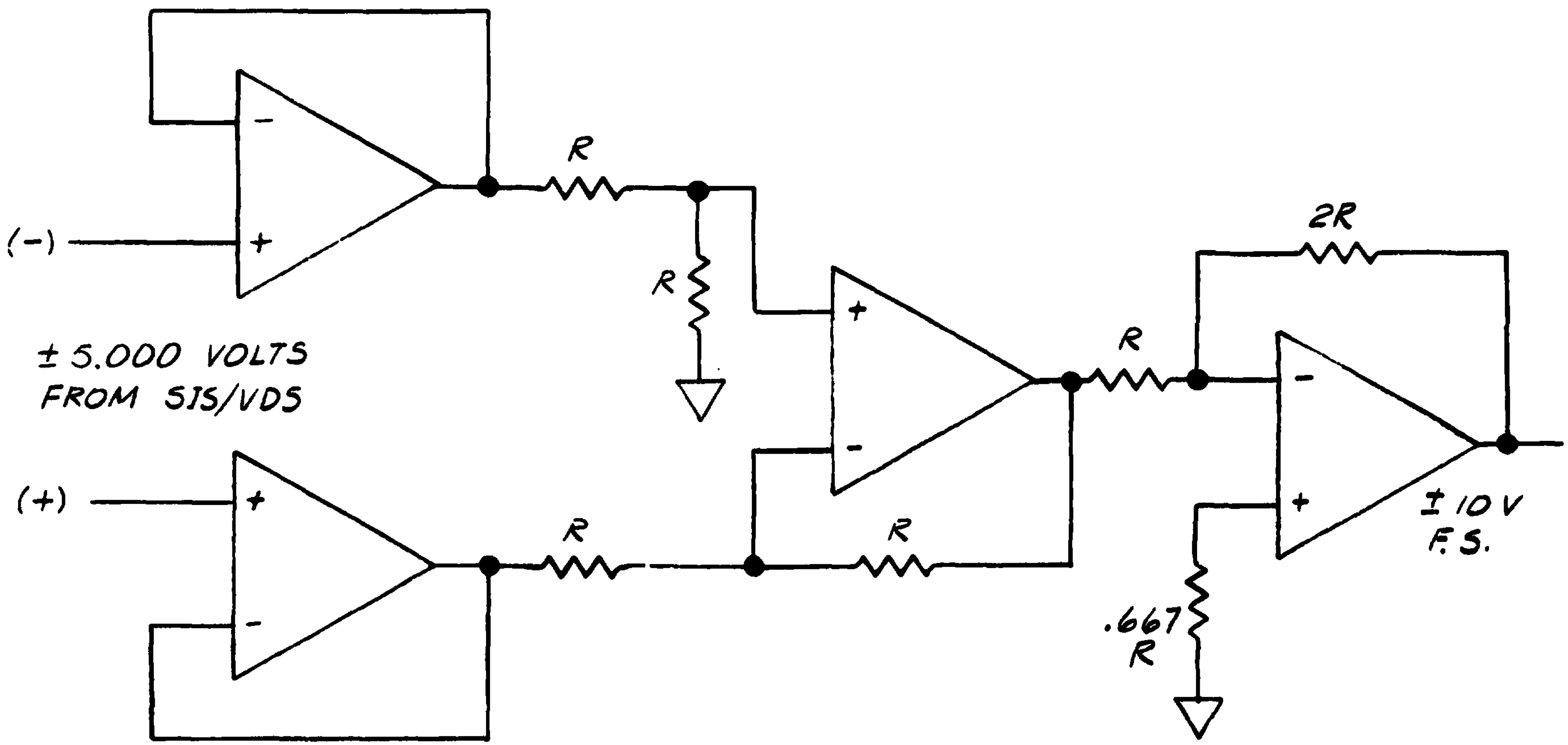
RATE/POSITION
SAS/TOC INTERFACE

LEC/CLF
12-2-75



INITIALIZATION   TOC/ASA INTERFACE

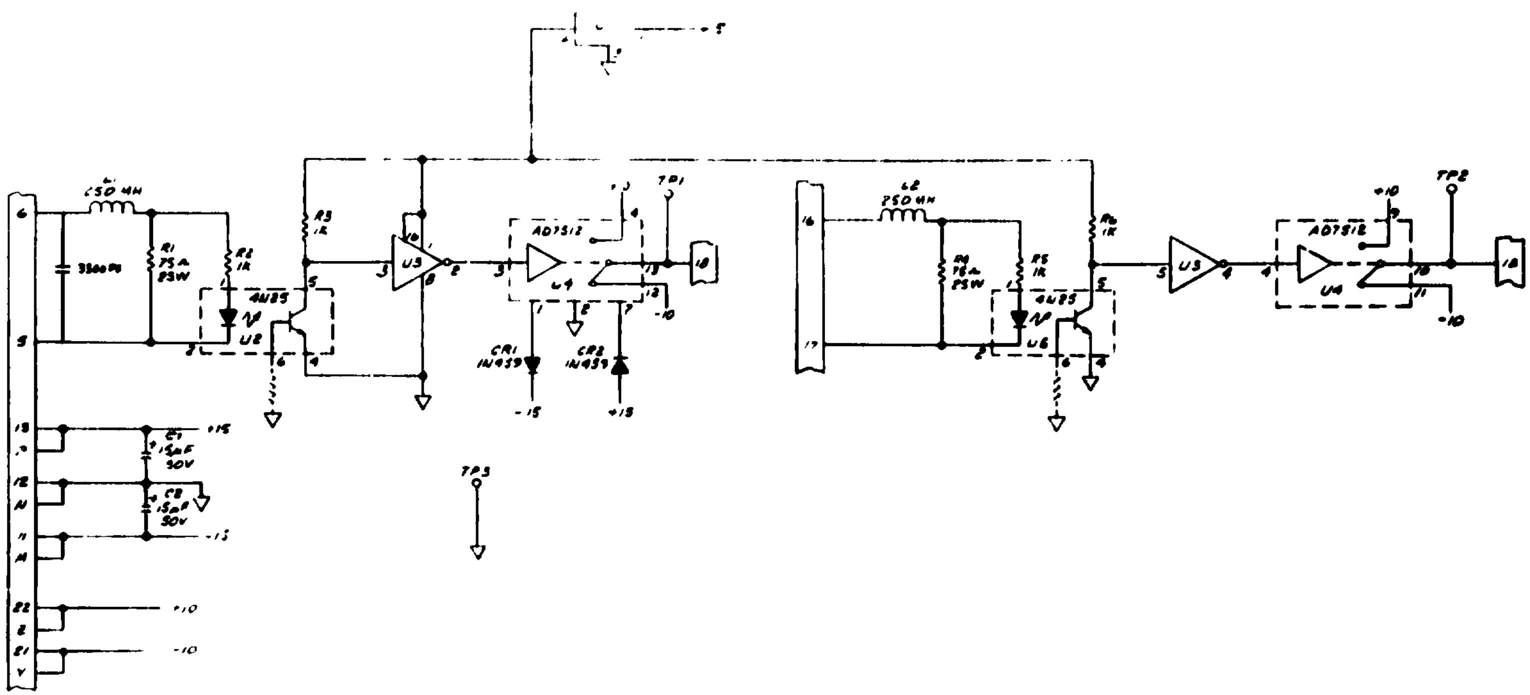
LEC/CLF
12/2/75



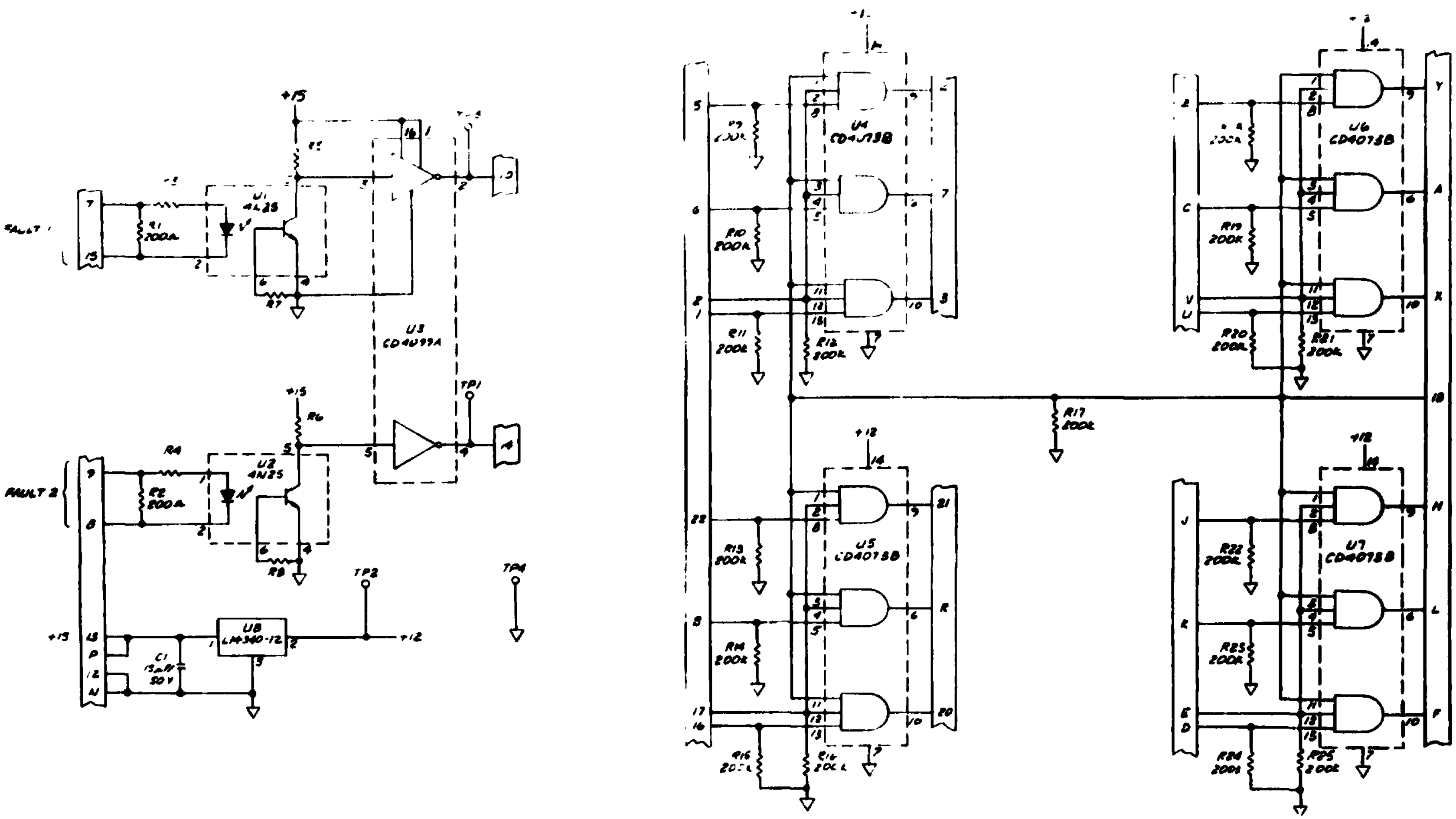
HINGE MOMENT SIS/SA INTERFACE

LEC/CLF
12/2/75

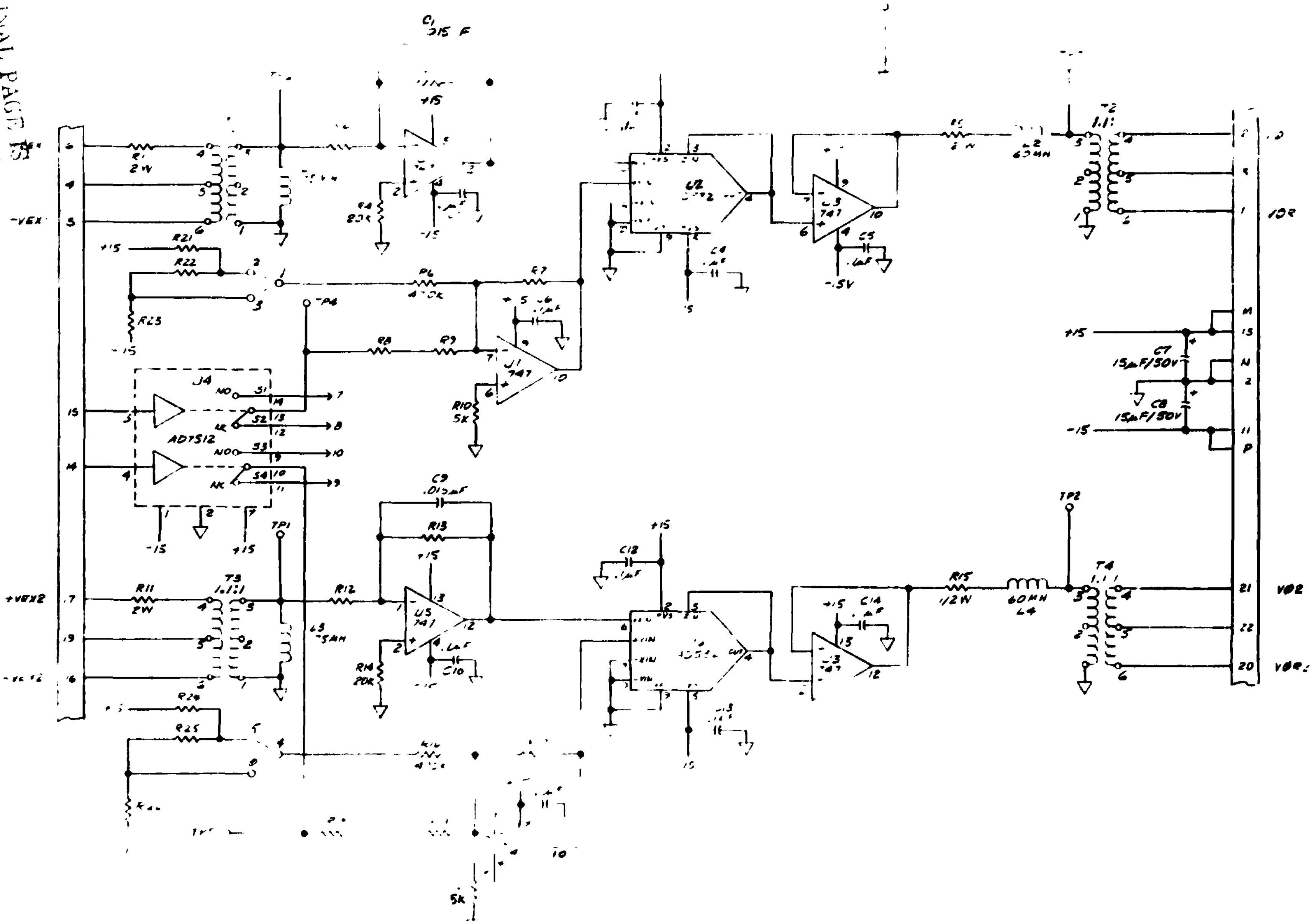
ISOLATION VALVE, INTERFACE, SIMULATOR ACTUATOR SUBSYSTEM



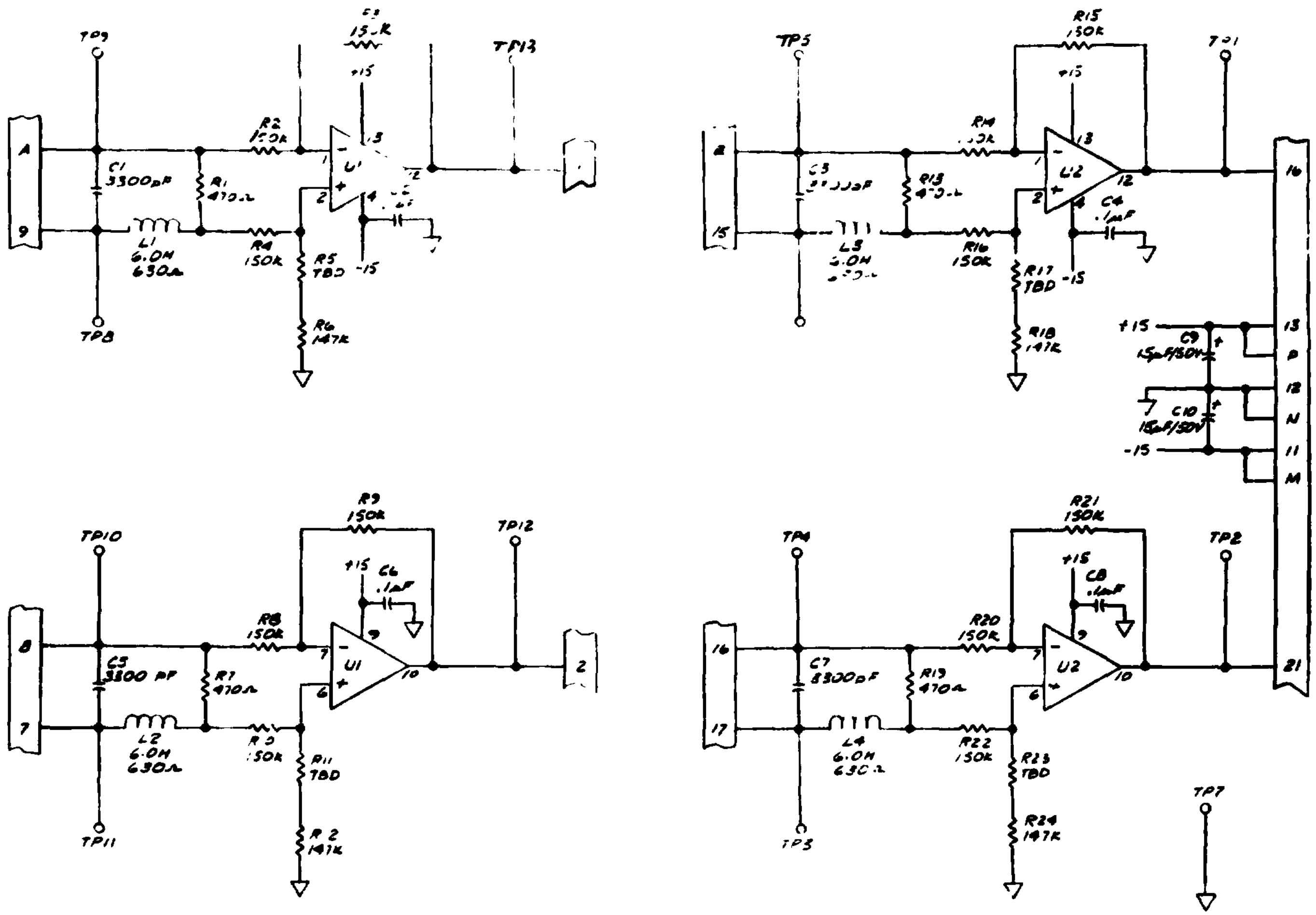
FAULT INSERTION, INTERFACE, SIMULATOR ACTUATOR, SUBSYSTEM



PRESSURE/POSITION TRANSDUCER SIMULATOR ACTUATOR SUBSYSTEM



MOTOR FLAP SECOND VALVE, INTERFACE, SIMULATOR ACTUATOR SUBSYSTEM



APPENDIX D

ELEVON CONTROL VALVE MODULE MEMORANDUM

LOCKHEED ELECTRONICS COMPANY, INC.
AEROSPACE SYSTEMS DIVISION
16811 EL CAMINO REAL ● HOUSTON, TEXAS 77058 ● TELEPHONE (AREA CODE 713) 488-0080

6 January, 1976
GC-5479-620

TO : H. Shelton
NASA-JSC/EG5

FROM : J. C. Barr
LEC-ASD/C08

SUBJECT : DEVELOPMENT OF MODEL FOR ELEVON CONTROL VALVE MODULE

REFERENCE : MINUTES OF MEETING, SHUTTLE ACTUATORS COORDINATION WORKING GROUP, DEC. 10, 1975.

The SAS design review for the Elevon resulted in several action items. Item 2 involved anomalies in the implementation model ΔPs time history trace for various inputs. Resolution of this item was assigned to J. Barr.

This document presents the method and results for resolution of action item 2. The paper contains two parts (1) the development and verification of a reduced model, and (2) a comparison of this reduced model with the implementation model that was presented in the design review. The new reduced model will add a slight degree of complexity to the hardware control valve module mechanization.

The anomalies were concerned primarily with the ramp (constant current) input. Mr. Jack Hoke, of Rockwell International, maintained that the ΔPs trace should be very similar for the full-up and reduced models. In order to resolve the discrepancy it was decided to redevelop the reduced model, with additional checks at each stage of the reduction.

The reduction was accomplished in three steps. The first step eliminated the second stage valve dynamics. The second step removed the flapper valve lag time. The third step added a first order lag to Xs. The full-up model and its response is shown in figure 1. The peak pressure is 34.8 psi.

The first reduction affected Xs, second stage valve position, and its velocity. The dynamics and stiction were eliminated, as was the flow feedback term to the flapper valve. The resulting control valve model and its step response is shown in figure 2. The peak pressure is 138 psi. at the time of the step input. Within 40 msec the response has settled to the full-up response.

The second reduction affected P_N, flapper valve pressure. The first order lag was eliminated. The resulting control valve model and its response is shown in figure 3. The peak pressure is 196.4 psi at the time of the step input. Within 40 msec the response has settled to the full-up response.

The final step affected Xs, second stage valve displacement. A first order lag term is added to improve the rate response. The secondary pressure spike of 196.4 psi shown in figure 3 has been reduced to 88.4. The resulting control valve model and its response is shown in figure 4.

Figure 4 is the recommended implementation model. The remainder of this paper presents a comparison of the model of figure 4 and the implementation model presented at the design review on December 10, 1975.

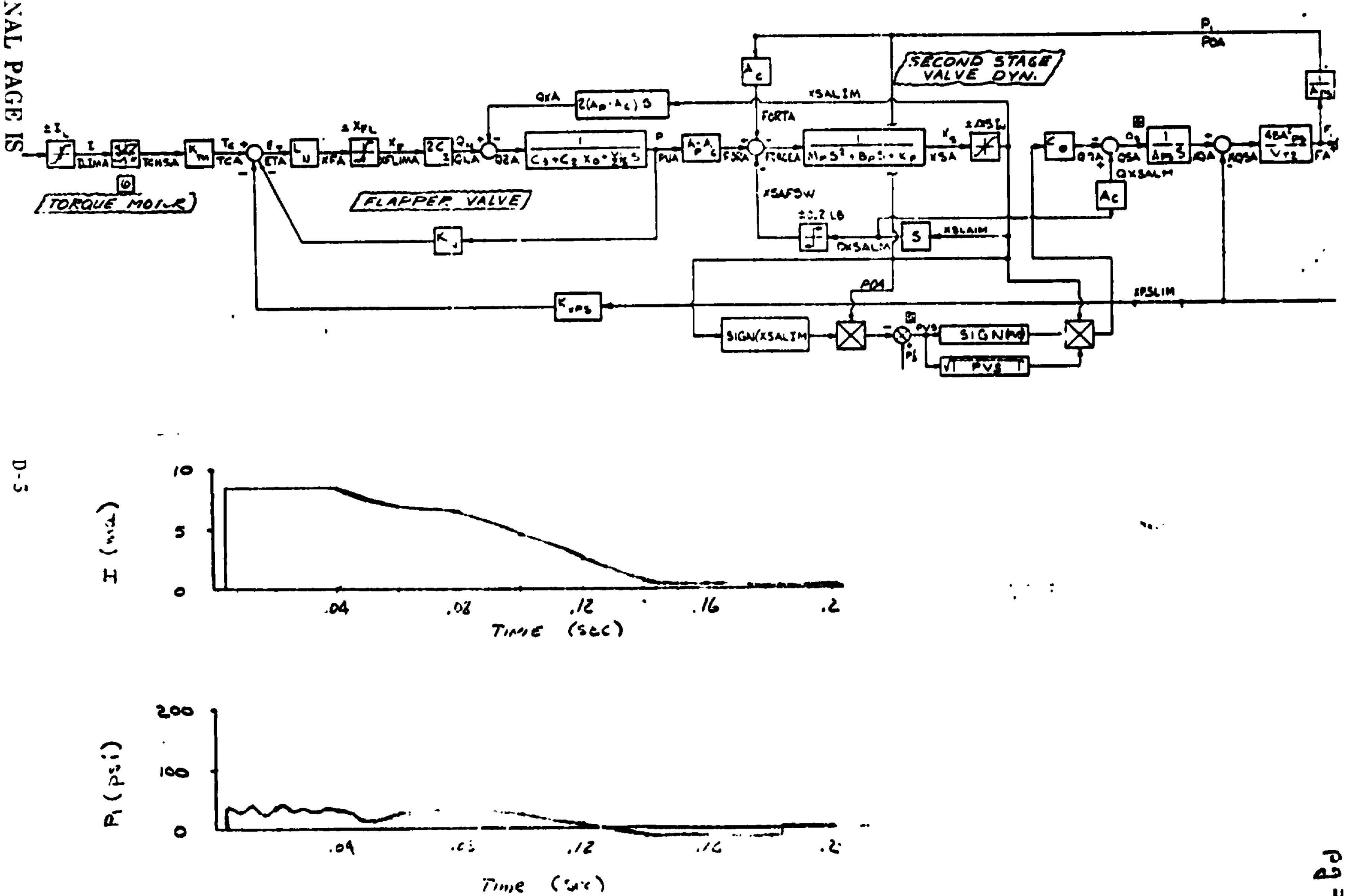


FIGURE 1 - FULL-UP MODEL

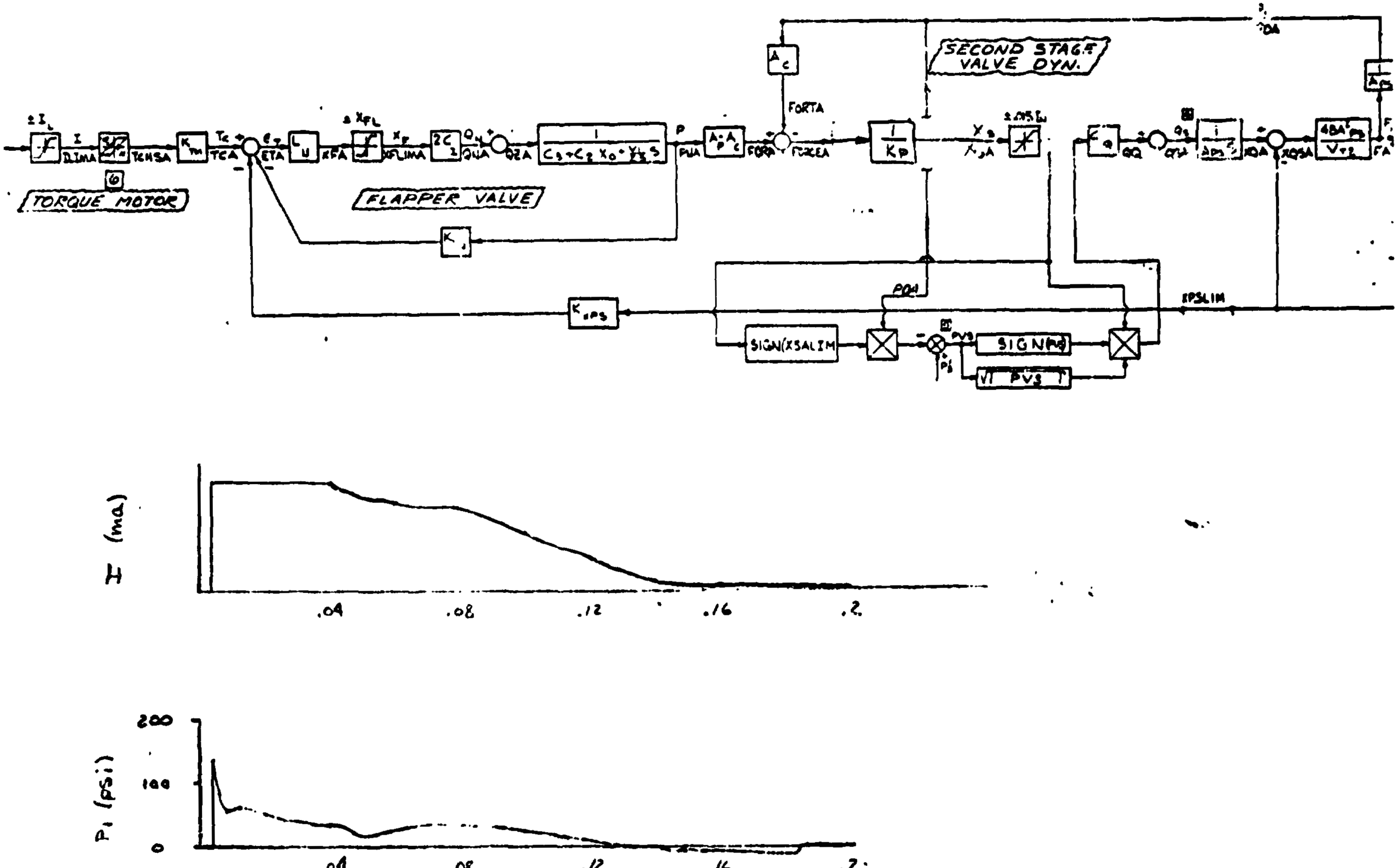


FIGURE 2 - REDUCTION OF 2ND STAGE VALVE

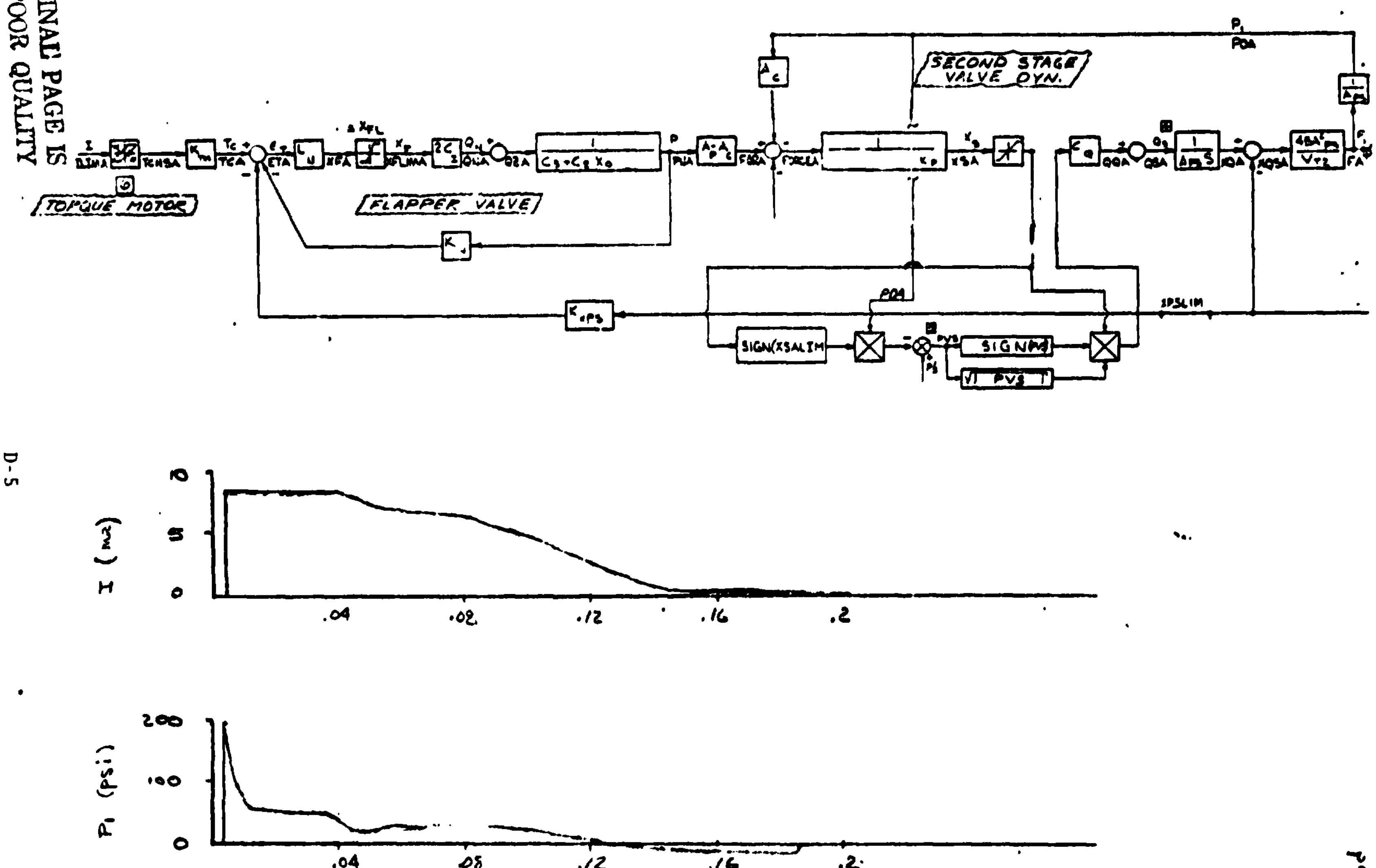


FIGURE 3 - REDUCTION OF FLAPPER VALVE

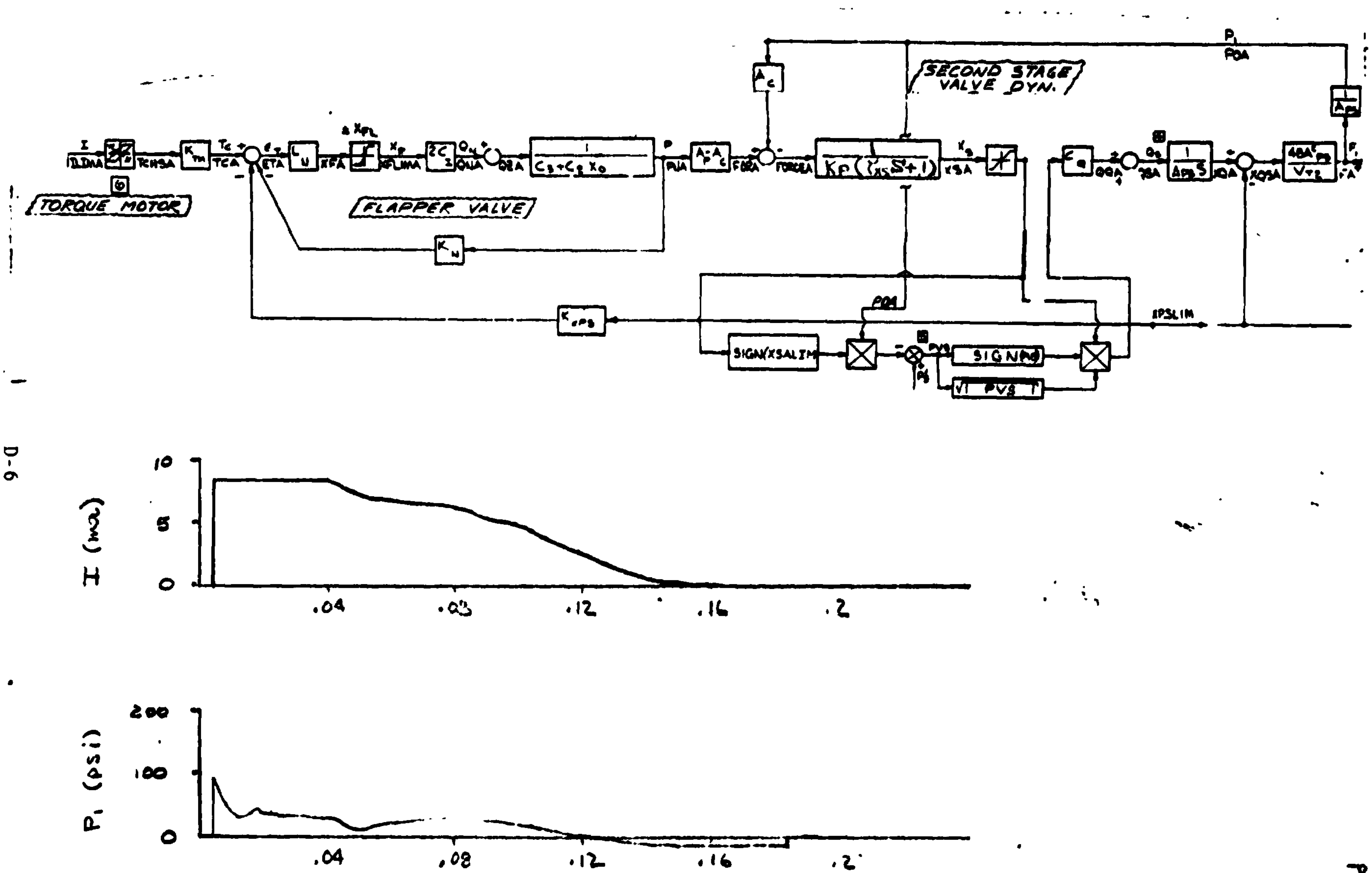


FIGURE 4 - FINAL REDUCED MODEL

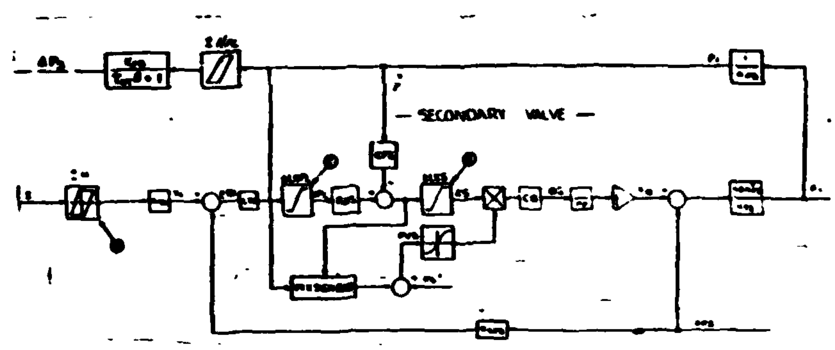
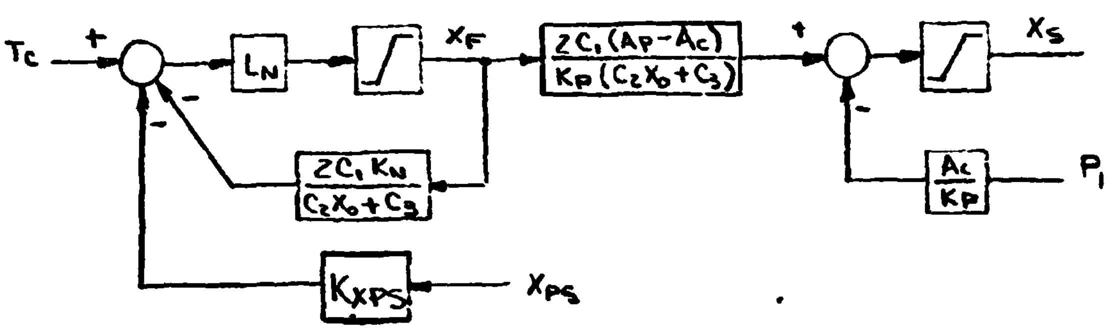


Figure 5.

Figure 5 is the implementation model that was presented at the Elevon design review. Figures 4 and 5 look quite different in the region of the flapper valve. Redrawing the flapper region of figure 4 and combining cascaded gains:



For the implementation model, figure 5, KQS was chosen by a small signal reduction which eliminated the XF limiter. The combined KQS and Kps were thus:

$$KQS = \frac{2C_1(A_p-A_c)}{K_p(C_2X_o+C_3+2C_1L_NK_N)} \qquad \text{. . . . (1)}$$

$$KPS = \frac{Ac}{K_p} \qquad \text{. . . . (2)}$$

And by the small signal assumption the XF limiter is insignificant to the model performance.

Large signal analyses run via computer programs demonstrated that the small signal assumption was invalid and the XF limiter was significant to the model. It is recommended that the implementation model be changed to that of figure 4.

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