(NASA-CR-144879) INVESTIGATION OF THE CROSS-SHIP COMPARISON MONITORING METHOD OF FAILURE DETECTION IN THE HiMAT RPRV (Kansas Univ. Center for Research, Inc.) 99 p HC A05/MF A01 CSCL 01C G3/05

N79-12064

Unclas 38692

NASA Contractor Report 144879

INVESTIGATION OF THE CROSS-SHIP COMPARISON MONITORING METHOD OF FAILURE DETECTION IN THE HiMAT RPRV

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December 1978

NASA Grant NSG-4012

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ACKNOWLEDGEMENTS

I would like to express my appreciation for the educational opportunity provided by the Dryden Flight Research Center and the National Aeronautics and Space Administration. A special thanks is in order to Dwain A. Deets, Chief of the Systems Analysis Branch, for his supervision and instruction and to the other members of the Branch for their support.

I would also like to express my appreciation to Professor Harry E. Talley, Department of Electrical Engineering, for his suggestions and encouragement.

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INVESTIGATION OF THE CROSS-SHIP COMPARISON MONITORING METHOD OF FAILURE DETECTION IN THE HiMAT RPRV

James A. Wolf

INTRODUCTION

The highly maneuverable aircraft technology (HiMAT) program will provide researchers in the military, industry, and the National Aeronautics and Space Administration (NASA) a developmental tool with which to test new concepts for the next generation fighter aircraft. The HiMAT remotely piloted research vehicle (RPRV) is a subscale prototype which will have enhanced maneuverability (sustained 8G turn, 0.9 M, at 7,900 m) using state-of-the-art technology (ref. 1).

The HiMAT RPRV has a basic design requirement that no single failure shall result in the loss of the vehicle (ref. 2). The method by which this requirement is met, with respect to failure detection in the canard, aileron, and elevator servosystems, is of some concern. The on-board primary microcomputer compares the surface position of corresponding right and left surfaces. This cross-ship comparison monitoring (CSCM) should detect a servosystem failure in time for a safe recovery. However, a failure indication for any other reason other than a failed servosystem (nuisance trip) would greatly hamper the research mission. By using a computer model of the HiMAT CSCM technique, the sensitivity to servosystem differences was evaluated. It is important that the

CSCM be evaluated to improve confidence in the performance and to define potential problems. This report gives a brief background of the HiMAT RPRV, describes the modeling of the servosystems and failure detection scheme, and discusses the possible effects of variations between servosystems.

SYMBOLS

ACT	actuator
A/D	analog-to-digital converter
AGE	auxiliary ground equipment
AMP	command amplifier
C	hydraulic control pressure, psi
CMDS	commands
COMP	computer
CSCM	cross-ship comparison monitoring
cm	centimeters
DEMOD	demodulator
DISCR	discrete
dB	decibel
deg	degree
EHSV	electrohydraulic servovalve
FB	feedback amplifier
FDBKS	feedbacks
F.S.	full stroke
f	frequency, Hz
G	acceleration of gravity, m/sec^2
G_A	actuator gain, in^{-2}
G_4	command gain, mA/V_{dc}

G_5	ram LVDT gain Vac/in
G_6	ram demodulator gain, Vdc/Vac
G_7	feedback gain, mA/Vdc
G_{11}	linkage gain, deg/in
G_V	servovalve gain, in^3/sec-mA
HiMAT	highly maneuverable aircraft technology
Hz	hertz
I_L	current limit, mA
I/O	input-output
IPCS	integrated propulsion control system
I_T	current threshold, mA
k	kth iteration
LOOP 1	first servosystem model
LOOP 2	second servosystem model
LT	left
LVDT	linear variable-differential-transformer
M	Mach number
m	meter
mA	millampere
ms	millisecond
N	noise source
n	number of bits
P_1	hydraulic source pressure, psi
POS	position
PROP	propulsion
R_1	hydraulic return pressure, psi
R_L	rate limit, in/sec

RPRV	remotely piloted research vehicle
RPV	remotely piloted vehicle
R_s	sample rate, samples/sec
RT	right
SOL	solenoid
s	Laplace variable
sps	samples/sec
T	iteration period
t	time, sec
t_t	transfer time delay
Vac	volts, ac
V_c	command voltage
Vdc	volts, dc
V_{DL}	left demodulator output signal
V_{DR}	right demodulator output signal
V_m	demodulator monitor signal
V_o	dc component of demodulator output
V_R	amplitude of demodulator ripple signal
X_L	ram stroke limit, in
δ_s	surface deflection, deg
$\dot{\theta}$	error rate, deg/sec
$\dot{\theta}_c$	commanded surface rate, deg/sec
θ_d	transfer delay error, deg
$\dot{\theta}_f$	failed surface rate, deg/sec
θ_{fs}	full stroke deflection range, deg
θ_q	quantization error, deg
θ_ℓ	initiation point of lock-up, deg

θ_s	safe limit
θ_{sr}	sample rate error, deg
θ_t	computer threshold limit

Subscripts:

i	input
o	output
k-1	previous iteration

HiMAT RPRV

A brief description of the HiMAT RPRV is given in the first section. The focus of the following sections is on the method of failure detection for the simplex servosystems which actuate the canard, aileron, and elevator control surfaces. Pertinent background information is given and some of the potential problems discussed.

Description

The HiMAT RPRV is a scaled version (.44) of an advanced technology fighter aircraft. There are numerous state-of-the-art concepts implemented in the design, such as the composite structure, close-coupled canards, and wingtip fins. Figure 1 illustrates the dimensions of the vehicle and the five types of control surfaces. The following subsections give an overview of the HiMAT RPRV and program, and because the subject of this report is the failure detection in the simplex servosystems, these systems are discussed in depth.

Overview. - In the primary flight mode the vehicle is controlled by the ground-based pilot in the cockpit of the Remotely Piloted Vehicle (RPV) facility (see figure 2). This facility provides the pilot with conventional displays using downlinked data from the HiMAT RPRV. Pilot commands are processed in the ground-based computer, then uplinked to the on-board microcomputer which outputs the command signals to the respective control surface actuators.

There are two on-board microcomputers in operation during the primary flight mode. This is the normal mode for maneuver and cruise research. The major functions are distributed be-

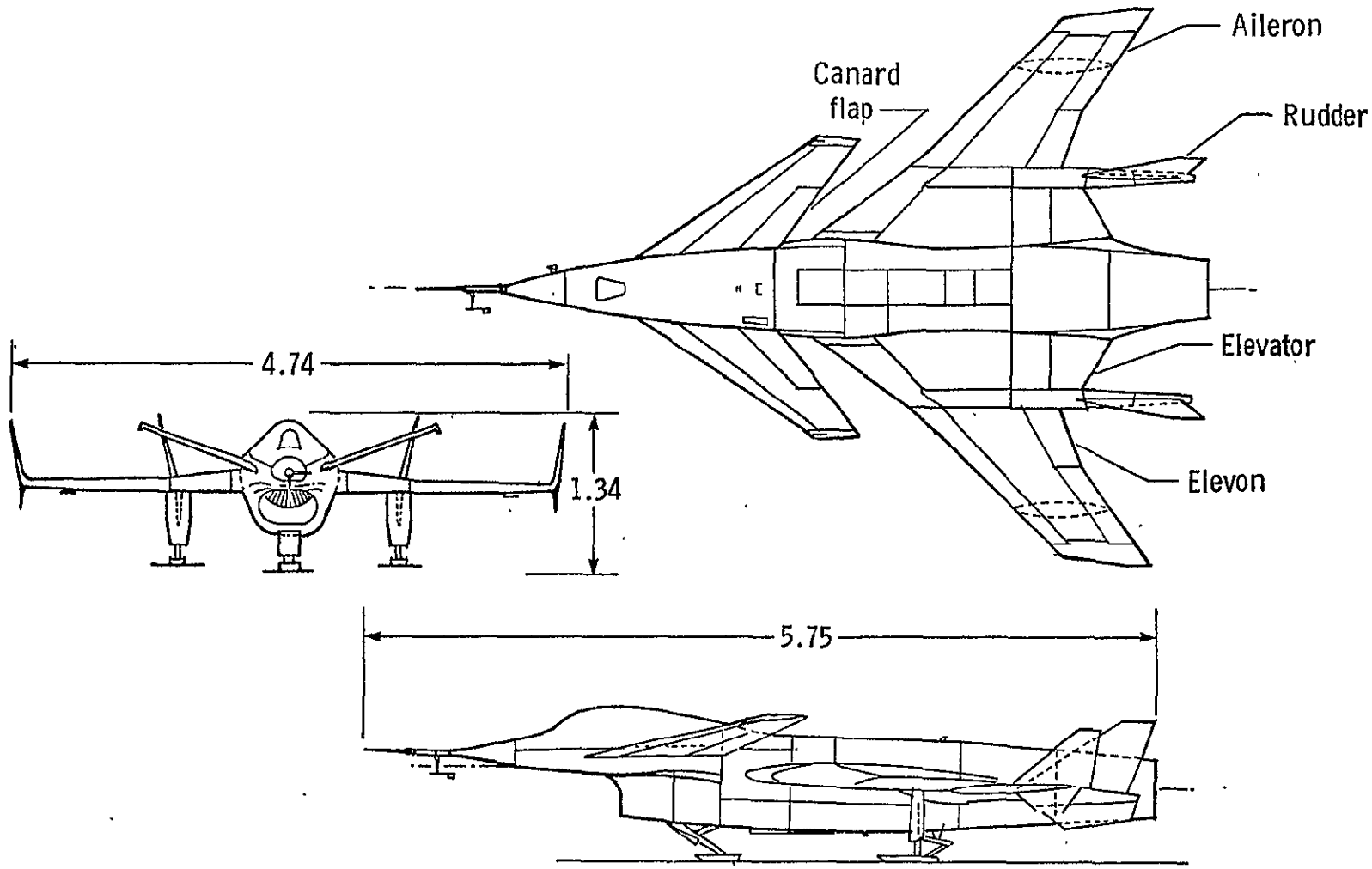


Figure 1.- Three-view drawing of HiMAT RPRV. Dimensions are in meters.

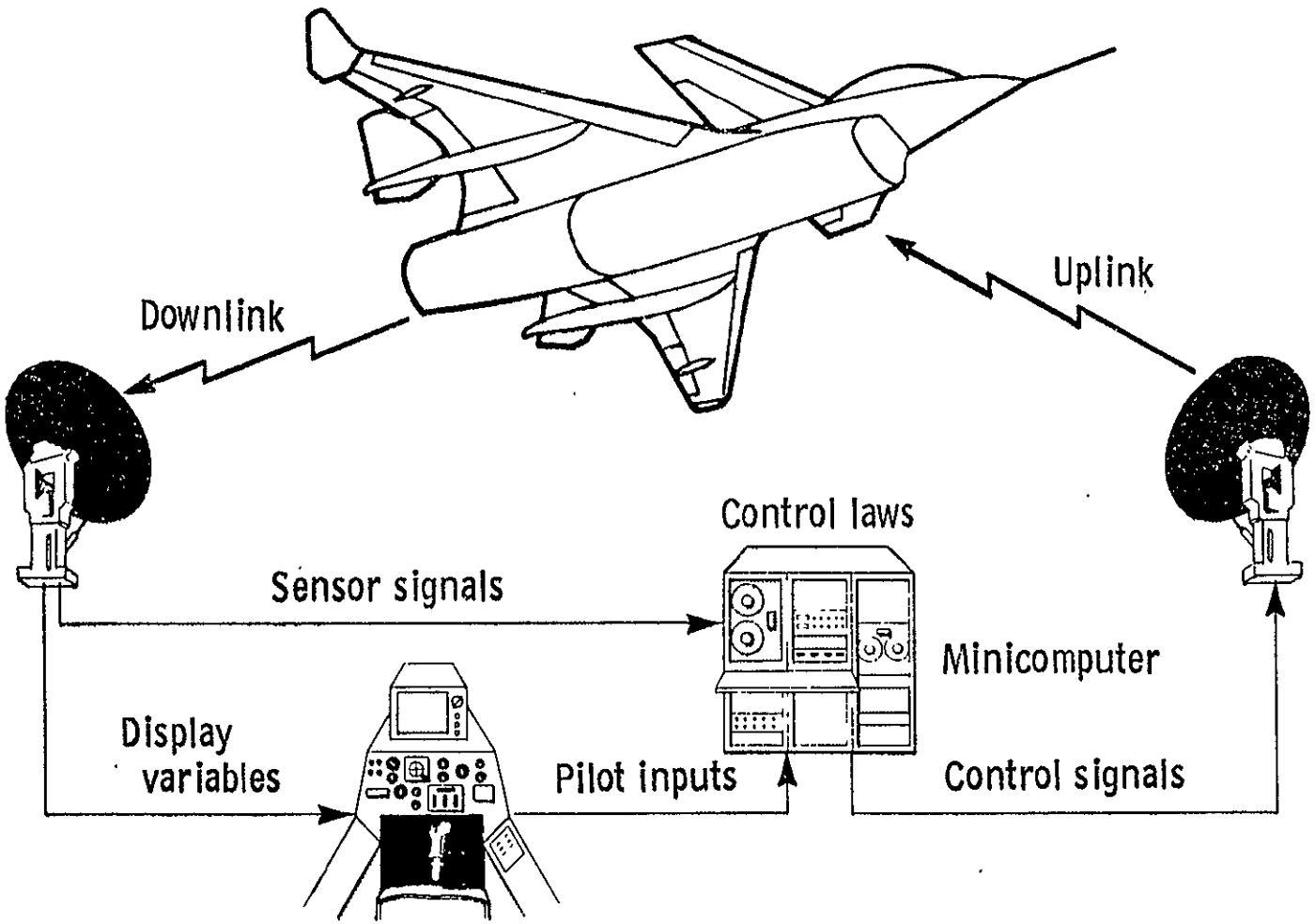


Figure 2.- Conceptual layout of RPRV operation with ground facility.

tween the two computers. One computer is termed the primary computer and one is termed the back-up computer. Although the back-up computer has a major function in the primary flight mode, the term "back-up" arises because, should a failure occur, there would be a transfer of some functions from the primary computer to the back-up computer. Functions that are not taken over by the back-up computer are halted. Table 1 shows the division of tasks between computers. Figure 3 is a block diagram of the on-board computer system (ref. 1).

If a function or element has an importance to the RPRV such that its failure would result in loss of the vehicle, it is defined to be a flight critical function or element. Flight critical functions or elements are dual redundant (i.e., on-board microcomputers, electrical power system, and rudder and elevon hydraulic systems).

Mission critical functions or elements are not essential to keeping the vehicle in flight (i.e., canards, ailerons, and elevators). However, a failure of one of these functions or elements, would constitute an immediate end to the research mission and a return to base. Effective failure detection of the mission critical functions or elements should prevent loss of the vehicle. As an example, take the case of a failure in a canard servosystem, the failure detection routine would:

1. Detect the failure
2. Begin the actuator locking sequence
3. Transfer control to the back-up computer

The back-up system would provide emergency return home capability using an on-board autopilot. The flight critical

MODE	PRIMARY COMPUTER PROCESSING TASKS	BACK-UP COMPUTER PROCESSING TASKS
Primary Flight Mode	- primary flight sensor data - control surfaces - uplink information - downlink information - failure detection	- integrated propulsion control system
Back-up Flight Mode	———	- back-up control surfaces - back-up autopilot - reduced IPCS - sensor data

TABLE 1

MAJOR FUNCTIONS OF THE PRIMARY

AND BACK-UP COMPUTERS IN THE PRIMARY AND BACK-UP CONTROL MODES

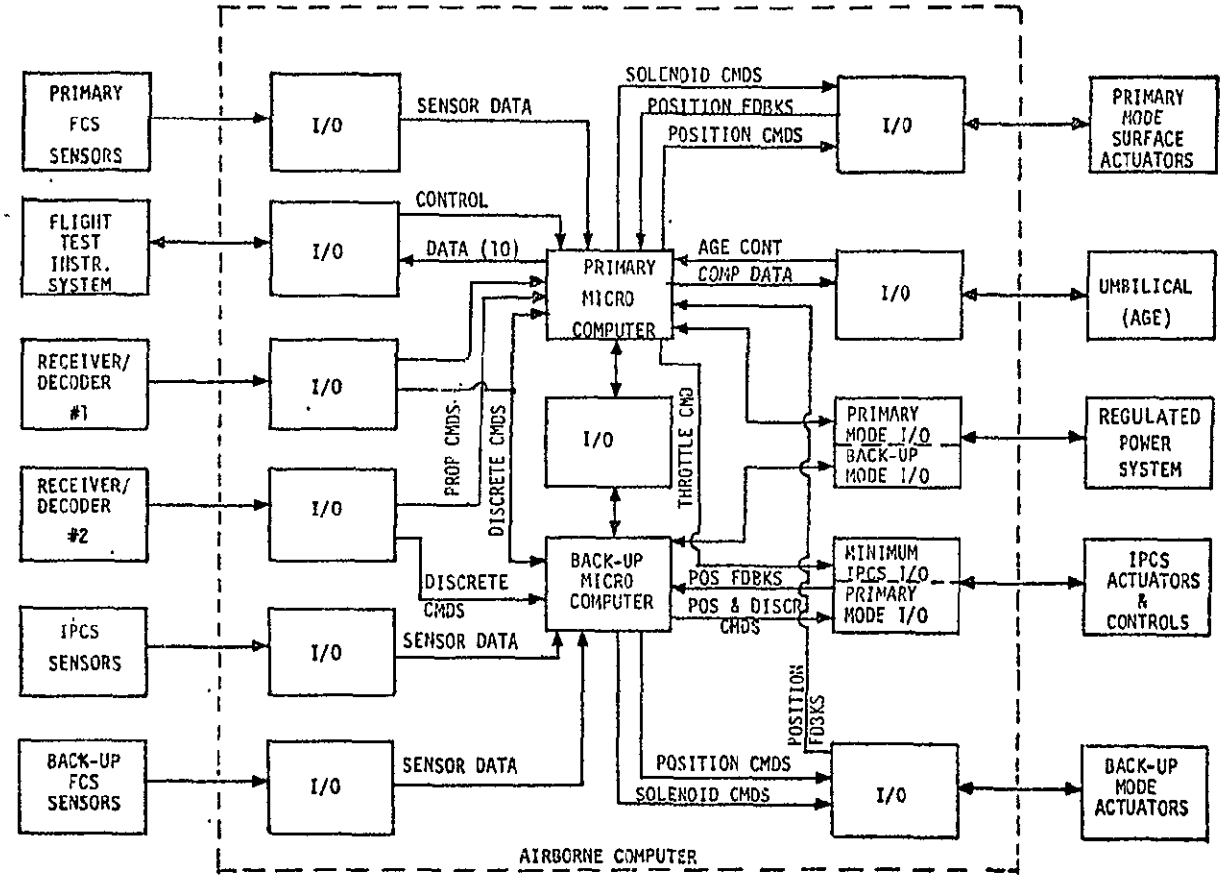


Figure 3.- Functional block diagram of the on-board computer system.

control surfaces (elevons and rudders) would be used to control the HiMAT RPRV back to a lakebed landing. The pilot can control the altitude variations, directions, and speed using discrete commands. The canards, ailerons, and elevators are hydraulically locked at a predetermined position.

Simplex servosystems. - The ten control surfaces of the HiMAT RPRV are positioned using hydraulic servoactuators. The mission critical surfaces (canards, ailerons, and elevators) have a single hydraulic supply and input. This is defined to be a simplex servosystem. Except for the elevator, which has a higher force output requirement (tandem actuator), they have a single actuator. This is shown in figure 4 which is a schematic of the simplex servoactuator. The control surface characteristics are shown in table 2. Notice that the canards can move symmetrically or antisymmetrically, but not combined.

Uplinked pilot commands are converted from a digital signal to an analog signal and fed to the commanded surfaces. The simplex servosystem is illustrated in figure 5 with a block diagram (ref. 3). Table 3 gives the corresponding gain values. The servoamplifier sums the command and feedback inputs and supplies a proportional output current to the electrohydraulic servovalve (EHSV). The EHSV controls the fluid flow rate to the actuator (ref. 4). The actuator provides the force output to move the control surface to the commanded position. The surface deflection rate is determined by the characteristics of the EHSV and actuator. Position feedback is derived from the output of the linear variable-differential transformer (LVDT) (ref. 5). The iron core of the transformer is attached to the actuator ram (see figure 4). The LVDT pri-

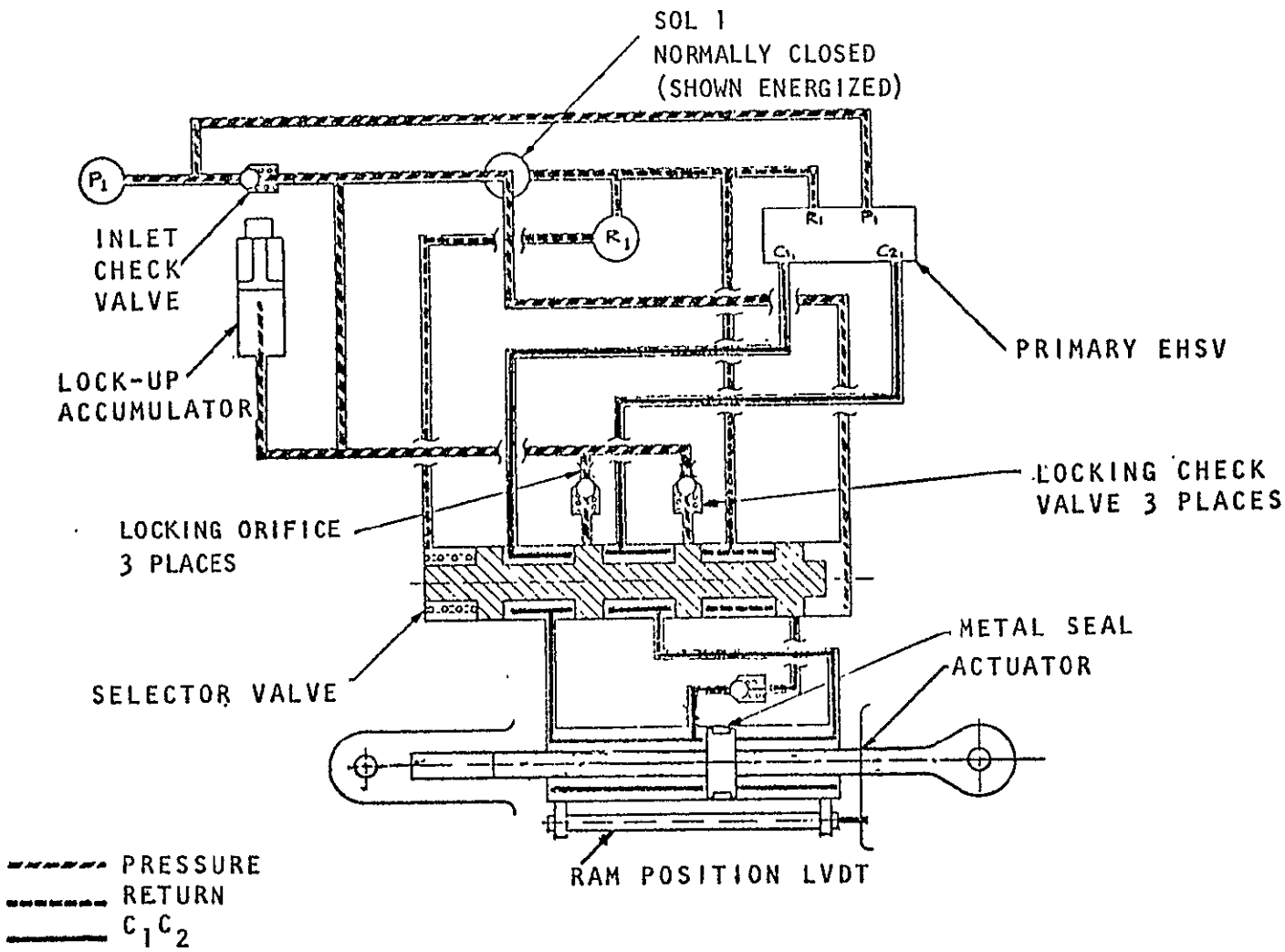


Figure 4.- Schematic of the simplex servoactuator.

	AILERONS	CANARDS	ELEVATORS
Servo-Actuator type	single input single actuator	single input single actuator	single input tandem actuator
Surface deflection	antisymmetric	antisymmetric or symmetric	symmetric
Maximum surface rate	90°/sec	90°/sec	90°/sec
Location on the vehicle	outboard wing surface	forward control surface	inboard wing surface

TABLE 2

CONTROL SURFACE CHARACTERISTICS

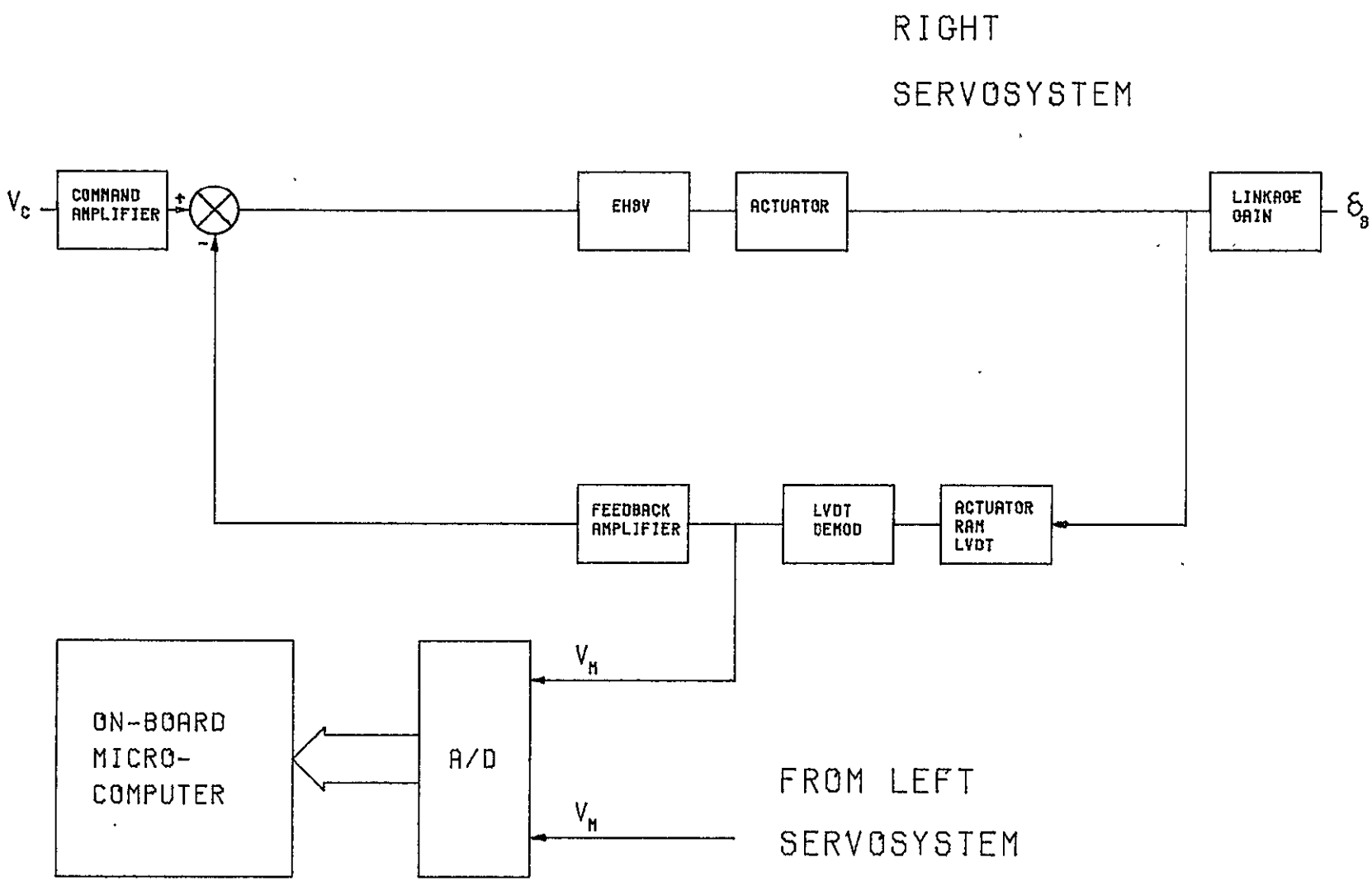


Figure 5.- Block diagram of the simplex servosystem and failure detection scheme.

Symbol	Canard	Aileron	Elevator	Units
G_V	0.636	0.636	1.503	$in^3/sec\text{-}mA$
G_A	0.909	0.909	0.455	in^{-2}
G_4	6.969	6.969	8.621	mA/V_{DC}
G_5	2.919	2.919	2.919	V_{AC}/in
G_6	3.824	3.824	3.824	V_{DC}/V_{AC}
G_7	12.346	12.346	10.471	mA/V_{DC}
G_{11}	39.72	39.72	34.13	Deg/in
I_L	± 4.0	± 4.0	± 4.0	mA
X_L	± 0.503	± 0.503	$^{+0.870}_{-0.595}$	in
R_L	2.312	2.312	2.733	in/sec
V_C	± 10	± 10	± 10	V_{DC}
δ_s	± 20	± 20	$^{+30}_{-20}$	Deg
Vm	± 5.60	± 5.60	± 8.176	V_{DC}

G_V - EHSV Gain
G_A - Actuator Gain
G_4 - Command Gain
G_5 - Ram LVDT Gain
G_6 - Ram Demond Gain
G_7 - Feedback Gain
Vm - Ram LVDT Monitor

G_{11} - Linkage Gain
I_L - Command Current Limit
X_L - Ram Stroke Limit
R_L - Ram Rate Limit
V_C - Actuator Command
δ_s - Surface Position

$G_2 = G_A \left[\frac{1}{s}\right]$

$\delta_s \begin{cases} + \rightarrow \text{TED} \\ - \rightarrow \text{TEU} \end{cases}$

TABLE 3

SIMPLEX SERVOSYSTEM GAINS AND SPECIFICATIONS

mary winding is excited by an oscillator as the actuator ram changes position (causing an accompanying change in the surface deflection). The iron core movement causes a change in the amplitude of the induced voltage in the secondary windings. This signal is demodulated and fed back to the servo-amplifier. The demodulated signal is also picked off and converted to a digital signal for use in the CSCM failure detection scheme. Command signals sent from the primary micro-computer and monitoring of the LVDT output occur at a rate of 53.33 hertz (18.75 millisecond cycle time). The command input will be a series of steps. The output of the LVDT demodulator will also appear to the computer as a series of steps, due to the sampling effect.

The simplex servosystem frequency response should be flat out to about 13 hertz under no-load conditions for movements up to thirty percent of full actuator ram stroke. The load frequency response specifications for displacements of up to ten percent full-stroke and thirty percent of maximum rate are listed below (ref. 3)

Attenuation - Less than +2 or -3 dB out to 3 hertz
Phase Shift - Less than 30 degrees out to 3 hertz

The servosystems will be operating under loaded conditions a majority of the time. The potential for a problem in the CSCM exists during flight due to aerodynamic loading of the control surfaces. This is because there are conditions in the flight envelope where the loading on one surface may be different from the loading on the opposite surface. This would mean a difference in response characteristics and thus, a chance for an error between corresponding surface position

indications. The failure detection system design must take this into account.

Failure Detection

The following subsections describe the design approach for the CSCM failure detection scheme. A general description of how it works, design constraints, and possible sources of error are given.

Design approach. - With the requirement that a single failure shall not result in loss of the vehicle, flight critical elements or functions must have a failure detection technique and back-up system. Mission critical elements or functions must have a failure detection technique that not only detects the failure but provides a return to stable flight (ref. 2). This is why the canards, elevators and ailerons are designed to move to a locked position after a first failure.

The failure detection and corrective action must be designed to respond quickly because of the fast response of the actuators and the vehicle. The actuators can move the control surfaces at a maximum rate of 90 degrees per second. Likewise, a failed servosystem could move the control surface at the maximum rate. It is possible, however, that a control surface could fail at the maximum rate while the surfaces are responding to a command signal. The resulting error rate between corresponding surface positions would exceed 90 degrees per second.

Functional description of the cross-ship comparison monitoring. - The failure detection method for the canards, ailerons, and elevators uses the fact that these surfaces move

either symmetrically or antisymmetrically. A comparison is made between respective right and left surface deflections. The on-board microcomputer monitors the comparison to determine the integrity of the aileron, canard, and elevator control surfaces.

The dc voltage output, from the actuator ram LVDT demodulator, proportional to the control surface position, is converted to a digital value (ref. 6). The microcomputer sums the values of each side, as in the case of the ailerons, to determine an error value. Because the canards move either antisymmetrically or symmetrically, depending on which mode they are in, the difference or sum of the surface positions is used. The error value is compared to the predetermined threshold value stored as a constant in the computer. Should the error value exceed the computer limit, a failure would be declared and an immediate switch to the back-up mode initiated.

The on-board microprocessor samples and processes the surface position information of the ailerons, elevators, and canards 53.33 times a second. The LVDT demodulator output voltage is converted to a 12 bit digital word. Since the demodulator voltage range is plus or minus 5.62 volts and the A/D converter is a plus or minus 10 volt type, the full A/D converter is not used (ref. 4).

A digital word representing a control surface position on one side is updated by the computer. Twenty-five microseconds later the opposite side is updated. This is done just prior to the output of a command signal so that any servosystem transients from the previous cycle will have died down. The

two double precision words representing corresponding surfaces are added or subtracted. The resulting quantity represents the error value between surfaces. The most significant eight bits are compared to the threshold constant stored in the computer. If the error value exceeds the threshold value, the resulting switch to back-up is initiated and the control surface lock-up sequence begins. The lock-up sequence and respective time delays are as follows:

1. Switch relay to de-energize solenoid - 15ms
2. De-energize locking solenoid - 20 ms
3. Hydraulic lag before check valves seat and ram begins to move to the lock-up position - 15ms

Thus, the total transfer delay before a failed actuator begins moving to the lock-up position is 50 milliseconds. For the case where one surface is fixed and the other is failing at the maximum rate of 90 degrees per second, the total transfer delay translates into an error between surfaces of 4.5 degrees. Therefore, the threshold value should be selected such that an additional error of 4.5 degrees would not exceed the safe limit.

Design Constraints on the cross-ship comparison monitoring technique. - The error between ailerons, canards, or elevators allowed before an unrecoverable flight condition occurs is seven degrees, ten degrees, and seven degrees, respectively. These values were determined based on simulation studies and on analysis of the effects for the case of one control surface fixed and the other failing hardover (90 degrees per second). However, it is possible for a failure to occur during positioning of the surfaces. This could result in an error rate of greater than 90 degrees per second.

There is a design compromise between the allowance of false failure indications, and the risk of losing the vehicle in the event a failure goes undetected. False failure indications, termed "nuisance trips", are very detrimental to the research mission because of considerable overhead involved in a single mission and the delays involved in troubleshooting the cause of the nuisance trip. Determination of a computer threshold value involves design trade-offs.

Two cases will be considered and the computer threshold values that are appropriate determined. The first case assumes the good control surface is fixed at some position when the opposite surface fails. The maximum error allowed before initiation of the lock-up sequence (θ_ℓ) is the difference between the safe limit allowance (θ_s) and the error accumulated due to the total transfer delay (θ_d).

$$\theta_d = t_t \times \dot{\theta}$$

$$\theta_\ell = \theta_s - \theta_d$$

To assure that the lock-up sequence begins some time before the error reaches θ_ℓ, the worst case should be assumed. This means that the quantization error due to the analog-to-digital conversion is at the maximum and the sampling instant is the one least desirable. The quantization error is equal to the amount of control surface deflection represented by the least significant bit. For the CSCM technique, the comparison error value is represented by an eight bit digital word. The quantization error in degrees is therefore,

$$\theta_q = \theta_{fs} / 2^n$$

where, θ_{fs} = full surface deflection range

n = number of bits used in the comparison to the threshold value

The least desirable sampling instant is at a point immediately before the error value reaches the computer threshold limit. The computer will not detect a failure until the next sample period. Therefore, the error accumulation in one sample period ($1/R_s$ where R_s is the sample rate) at the specified error rate ($\dot{\theta}$) is

$$\theta_{sr} = \dot{\theta}/R_s$$

Thus, the computer threshold limit (θ_t) together with the quantization (θ_q) and sample rate error (θ_{sr}) should be less than the maximum error allowed before initiation of the lock-up sequence (θ_ℓ) or:

$$\theta_t = \theta_\ell - \theta_{sr} - \theta_q$$

Figure 6 illustrates the error rate between surfaces, the worst-case quantization and sample rate error, and the required threshold limit.

The second case is that in which the good control surface is not fixed, but moving in such a way so as to produce a greater error rate than 90 degrees per second. The error rate ($\dot{\theta}$) is now equal to the sum of the failed surface rate ($\dot{\theta}_f$) and the commanded surface rate ($\dot{\theta}_c$),

$$\dot{\theta} = \dot{\theta}_f = \dot{\theta}_c$$

The computer threshold limit is calculated as described in the first case. Table 4 gives the computer threshold limit values for the canards, ailerons, and elevators for the 90 degrees

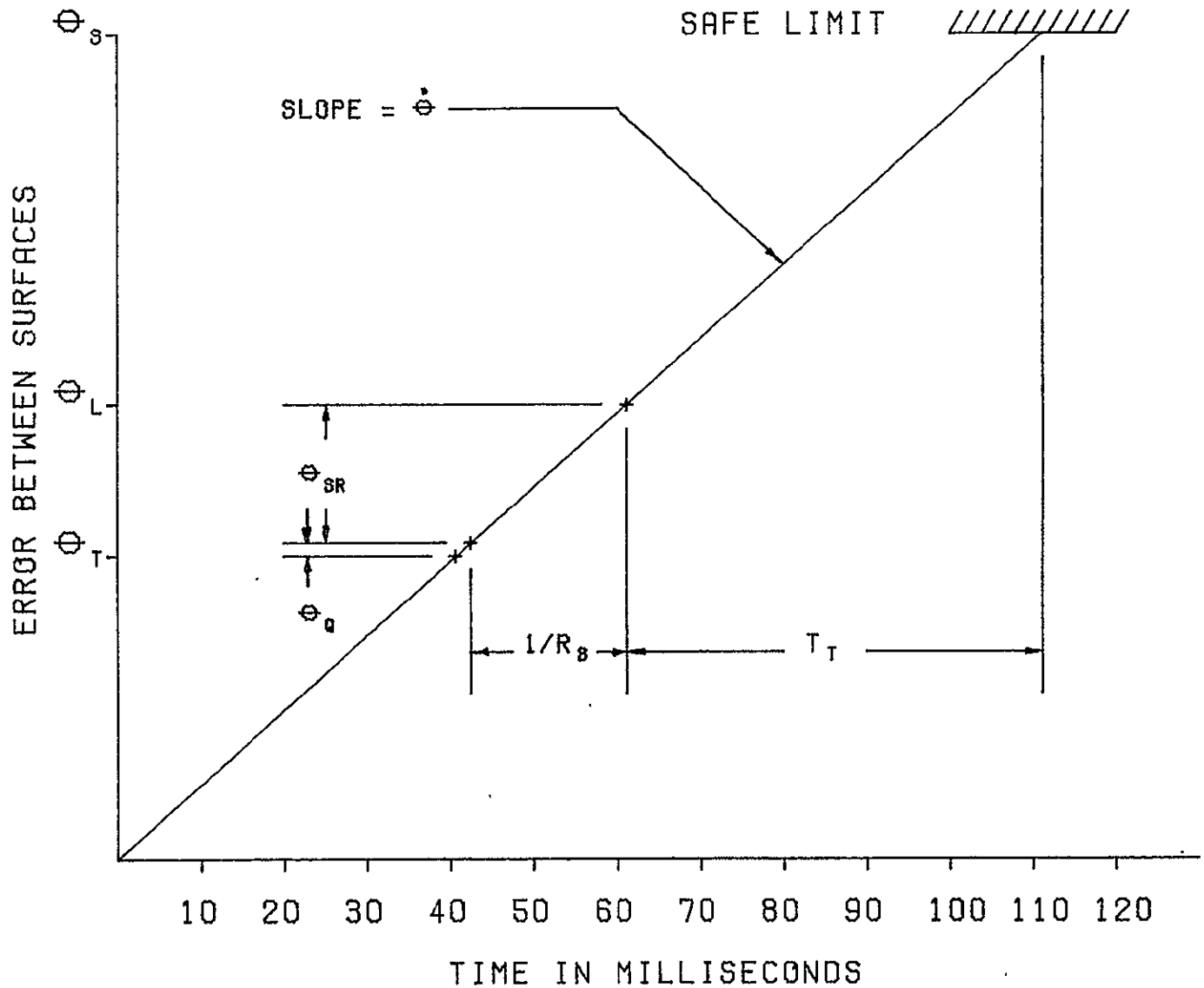


Figure 6.- Determination of the computer threshold limit.

	CANARDS		ELEVATORS		AILERONS	
ERROR RATE (DEGREES/SEC) $\dot{\theta}$	90	95	90	95	90	95
INITIATION POINT OF LOCK-UP θ_ℓ	5.5	5.25	2.5	2.25	2.5	2.25
TRANSFER DELAY ERROR (DEGREES) θ_d	4.50	4.75	4.50	4.75	4.50	4.75
SAMPLE RATE ERROR (DEGREES) θ_{sr}	1.69	1.78	1.69	1.78	1.69	1.78
QUANTIZATION ERROR (DEGREES) θ_q	.16	.16	.20	.20	.16	.16
SAFE LIMIT (DEGREES) θ_s	10	10	7	7	7	7
COMPUTER THRESHOLD LIMIT (DEGREES) θ_t	3.65	3.31	0.69	0.35	0.65	0.31

TABLE 4

SUMMARY OF PARAMETERS USED IN

DETERMINING COMPUTER THRESHOLD LIMITS

per second error rate case and for a 95 degrees per second error rate, illustrating the second case. It is evident that the calculated computer threshold limit for the elevators and ailerons is cause for concern. The total transfer delay accounts for a considerable amount of error. A reduction in this delay would allow the computer threshold limit to be increased. This might be accomplished by using a different switching relay to de-energize the locking solenoid. A reduction in the 20 millisecond de-energizing time to 4 milliseconds may be possible with a resulting increase in the necessary computer threshold limit (θ_t) of 1.44 degrees. The availablity of the faster switching relay is not likely to be a problem.

The sample rate error (θ_{sr}) is fixed because of constraints on the on-board computer loading. Since the computational load is near the maximum, any additional increase in sampling is not feasible. The quantization error (θ_q) could be reduced if the full range of the analog-to-digital converter were used and the full 12 bits instead of the most significant 8 bits were used. This would increase the computational loading to some degree, however, and the elimination of this error may not justify the additional loading. The advantage of increasing the threshold limit is the buffering effect created. Errors due to nonidentical unfailed servosystems are less likely to be a source of nuisance trips if there is a sufficient buffer band.

Possible sources of comparison errors in unfailed servosystems. - Any characteristic which is not identical between

corresponding servosystems is a source of comparison error. For example, the gains of each component in one servosystem may differ from those of the other servosystem due to manufacturing tolerances. In flight, the servosystem differences might be caused by aerodynamic loading. Electrical properties in corresponding components will be different. These types of differences give rise to error sources such as EHVS threshold error, servosystem hysteresis error and rate limit error.

LVDT demodulator ripple error. - Each servosystem LVDT demodulator has a ripple signal superimposed on it. These signals are from a single 1800 hertz oscillator and therefore, they will be in phase. As described earlier, the demodulator output sampling for corresponding surfaces occurs twenty-five microseconds apart.

Each right and left demodulator output is equal to the sum of the dc voltage, V_o, and the approximately sinusoidal ripple voltage, $V_r \sin(360ft)$. The frequency, f, is the oscillator frequency and the ripple amplitude, V_R, is equal to $0.071|V_o|$ (ref. 3). The sampling time difference, with respect to the error between demodulator outputs, can be thought of as a phase difference between corresponding right and left demodulator output signals, V_{DR} and V_{DL}. Therefore, the right and left demodulator outputs are,

$$V_{DL} = V_o + V_R \sin(360ft) \tag{1}$$

$$V_{DR} = V_o + V_R \sin(360f(t + 2.5 \times 10^{-5}) \tag{2a}$$

or,

$$V_{DR} = V_o + V_R \sin(360ft + 16.2) \tag{2b}$$

Two types of errors due to the ripple signal could occur.

One type would be characteristic of the symmetrically moving surfaces and the other would be characteristic of the antisymmetrically moving surfaces.

Taking the case of the symmetrically moving surfaces, the difference of the right and left demodulator outputs would be determined in the on-board microcomputer. All other things being equal (neglecting the analog-to-digital conversion effects), the error value determined would be the difference in the two ripple signal equations, 1 and 2b.

$$\text{ripple error} = V_R\left[\sin(360ft) - \sin(360ft + 16.2)\right] \tag{3}$$

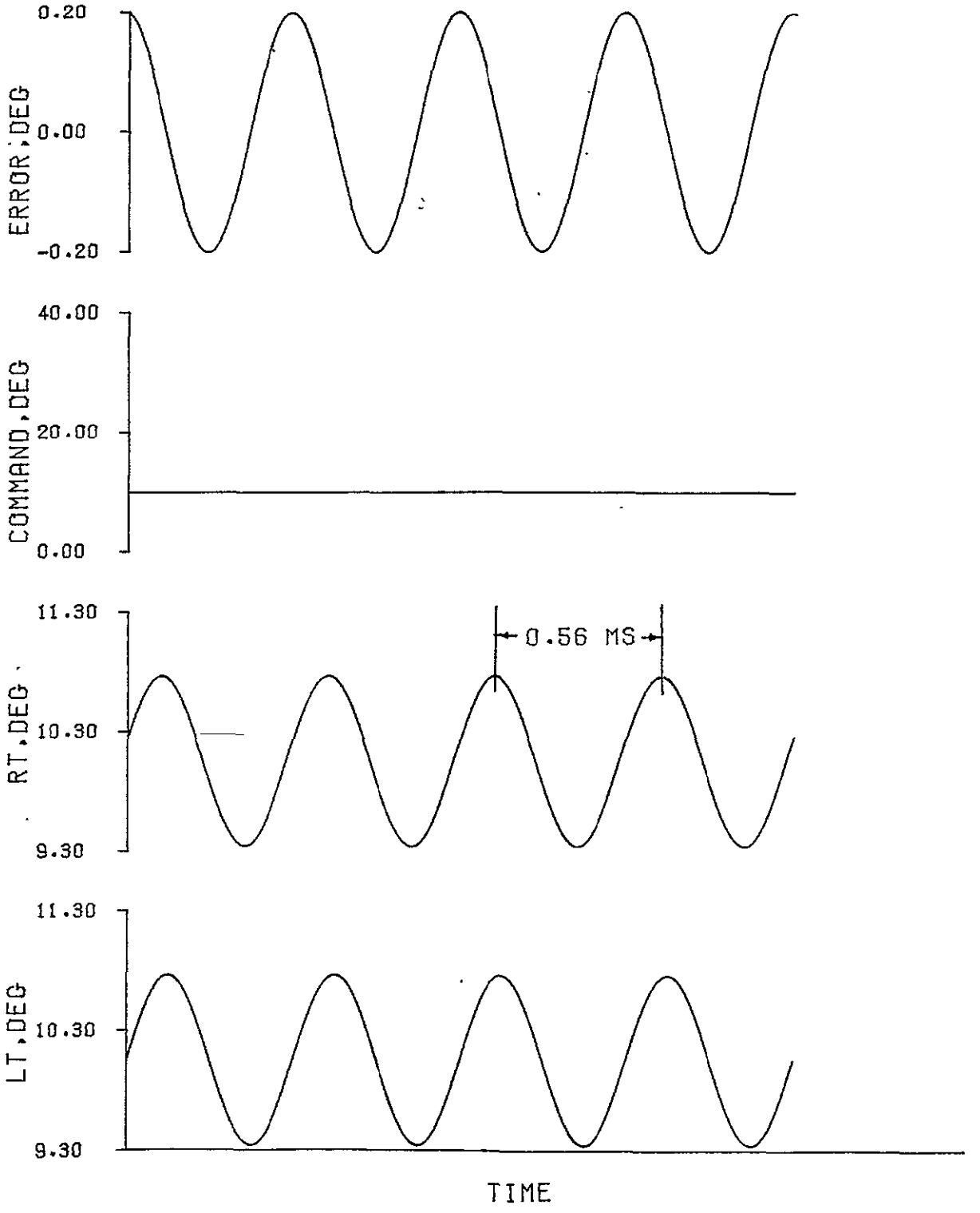
Figure 7a illustrates the error value for a plus 10 degree surface deflection.

For the case of the antisymmetrically moving surfaces, the right and left outputs have opposite polarity and so they would be added to produce an error signal. The error value would be the sum of equations 1 and 2b.

$$\text{ripple error} = V_R\left[\sin(360ft) + \sin(360ft + 16.2)\right] \tag{4}$$

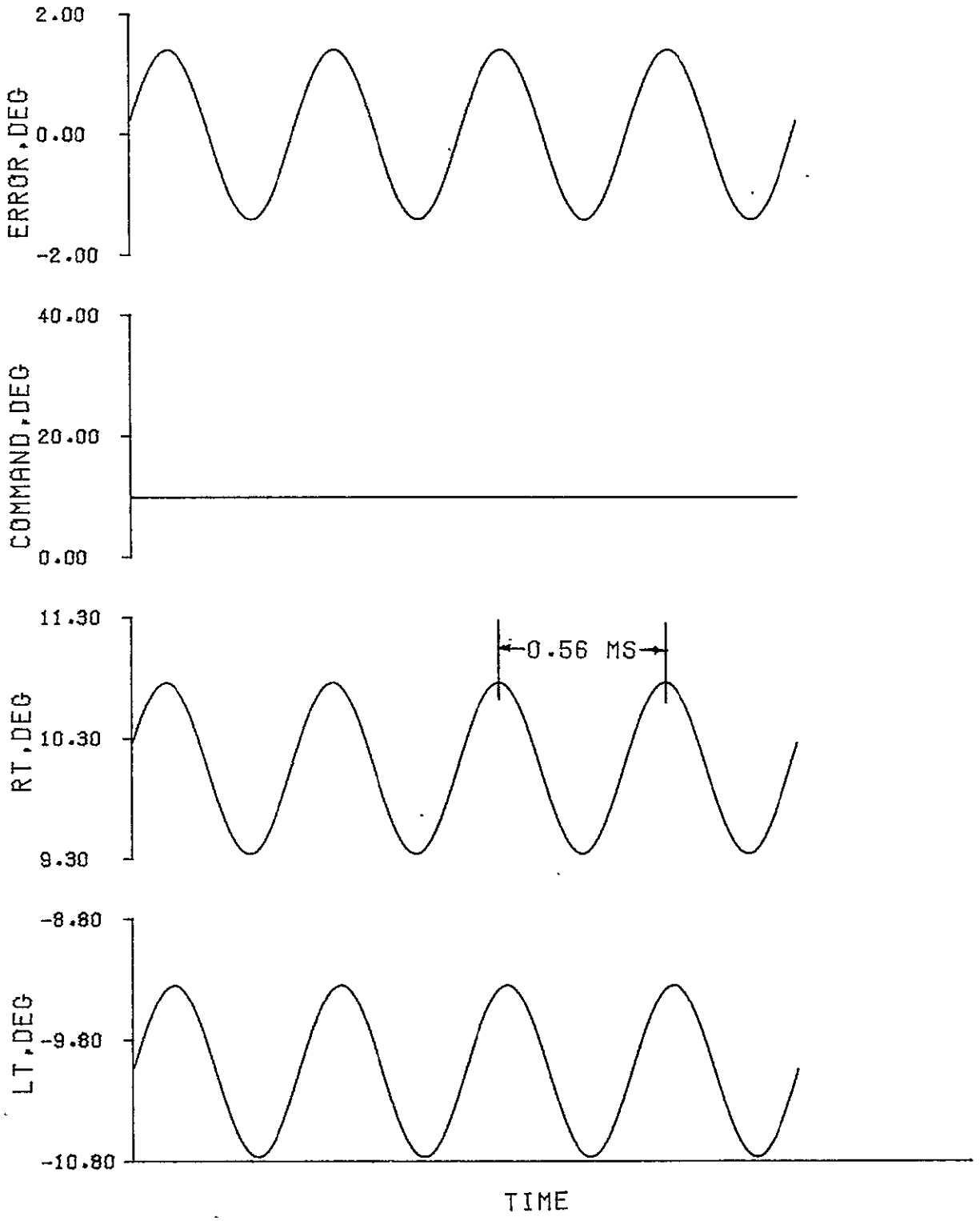
Figure 7b illustrates the error value for a plus and minus 10 degree surface deflection.

The worst-case ripple error for symmetrically deflected surfaces, deflected 20 degrees, would be significant. The worst-case sampling instant would occur at a point in time when the argument of the sine wave is at minus 8.1 degrees. After a 25 microsecond delay, when the argument of the sine wave is plus 8.1 degrees, the opposite position output would be sampled. According to equation 3, the ripple error magnitude



(a) Symmetric 10 degrees deflection.

Figure 7.- Left and right ripple signals shifted 25 microseconds



(b) Antisymmetric 10 degrees deflection.

Figure 7.-Concluded.

would be approximately 0.11 volts which corresponds to a false error between surface positions of approximately 0.4 degrees. This would be a potential source of nuisance trips because of the comparable value to the computer threshold limit for symmetrically moving surfaces. A possible solution to this condition would be to filter the LVDT demodulator output with a low-pass filter to attenuate the ripple signal.

The worst-case ripple error for antisymmetrically moving surfaces, deflected 20 degrees, would be more severe. The worst-case sampling is at a point in time when the first sample is taken just before the ripple signal reaches a peak value. The first position output would be sampled when the sine wave argument is 81.8 degrees. After the cycle delay, the opposite position output would be sampled, and again the argument would be 81.8 degrees. Using equation 4 the ripple error magnitude would be approximately 0.78 volts. This corresponds to a false indication of approximately 2.8 degrees, an excessive error. Again, a possible solution might be to filter the LVDT demodulator with a low-pass filter to attenuate the ripple signal, and thus, the error. Filtering, however, would involve additional hardware and analysis. This presents a problem because of an already compacted hardware arrangement.

For small surface deflections (less than one degree) the quantization error masks the ripple error for both symmetric and antisymmetric surfaces. Increasing deflections cause the ripple error for antisymmetric surfaces to dominate. The ripple error for symmetric surfaces is not a factor for a deflec-

tion under 8.0 degrees, due to the quantization error.

The effect of the ripple error in both cases would be to increase the probability of nuisance trips. For large surface deflections and computer threshold values as calculated, it is almost certain that a nuisance trip would occur. Filtering the demodulator output appears to be the most effective solution to this problem.

COMPUTER MODEL

The advantages of using a computer program to model the CSCM technique are listed below:

- Straightforward implementation of nonlinear as well as linear characteristics
- Amount of error that each component variation contributes is readily identified
- Servosystem changes can be made quickly and easily
- Data can be easily formated for automatic plotting

The formulation of the FORTRAN program used for evaluating the CSCM technique is discussed. The initial linear model is described after which the non-linear affects are added and the resulting model described.

Linear Model

A linear model was formulated to which other elements were included to more closely represent the actual servosystem. Once the servosystem was modeled the CSCM technique was represented using two servosystem models. Ease of including nonlinear blocks was a design goal for the linear model. A brief description of the servosystem and the characteristics of the components are given. Simplifying assumptions and

verification of the model performance is described.

Description. - The objective, when modeling the servosystem and subsequently the CSCM technique for failure detection, was to match the model behavior as closely as possible to the physical system behavior, within the anticipated operating range. For the physical system with command signal frequencies of up to 13 hertz, the unloaded servosystem response was very near that of an ideal low-pass filter (ref. 3). The servosystem actuator dynamics contribute a closed-loop pole at 13 hertz. The other servosystem elements have dynamic response characteristics as follows (ref. 3):

Servoamplifier (for signals up to 20% of rated output current) $G_4\left(\frac{628}{s + 628}\right)$

EHSV $G_V\left(\frac{580}{s + 580}\right)\left(\frac{5406}{s + 5406}\right)^1$

LVDT Demodulator $G_6\left(\frac{628}{s + 628}\right)$

The model of the servosystem was structured such that each mathematical expression in the code corresponded to a component of the actual servosystem. Initially the inputs and outputs were zero. One iteration of the code corresponded to one time increment and generated one set of output values. A flowchart of the model is shown in figure 8. For the first iteration the feedback value was assumed to be zero. The input to the EHSV block was then equal to just the command amplifier output. As outputs were calculated, the input to the next block was set equal to the output of the preceding block. The loop was closed after the first iteration because the

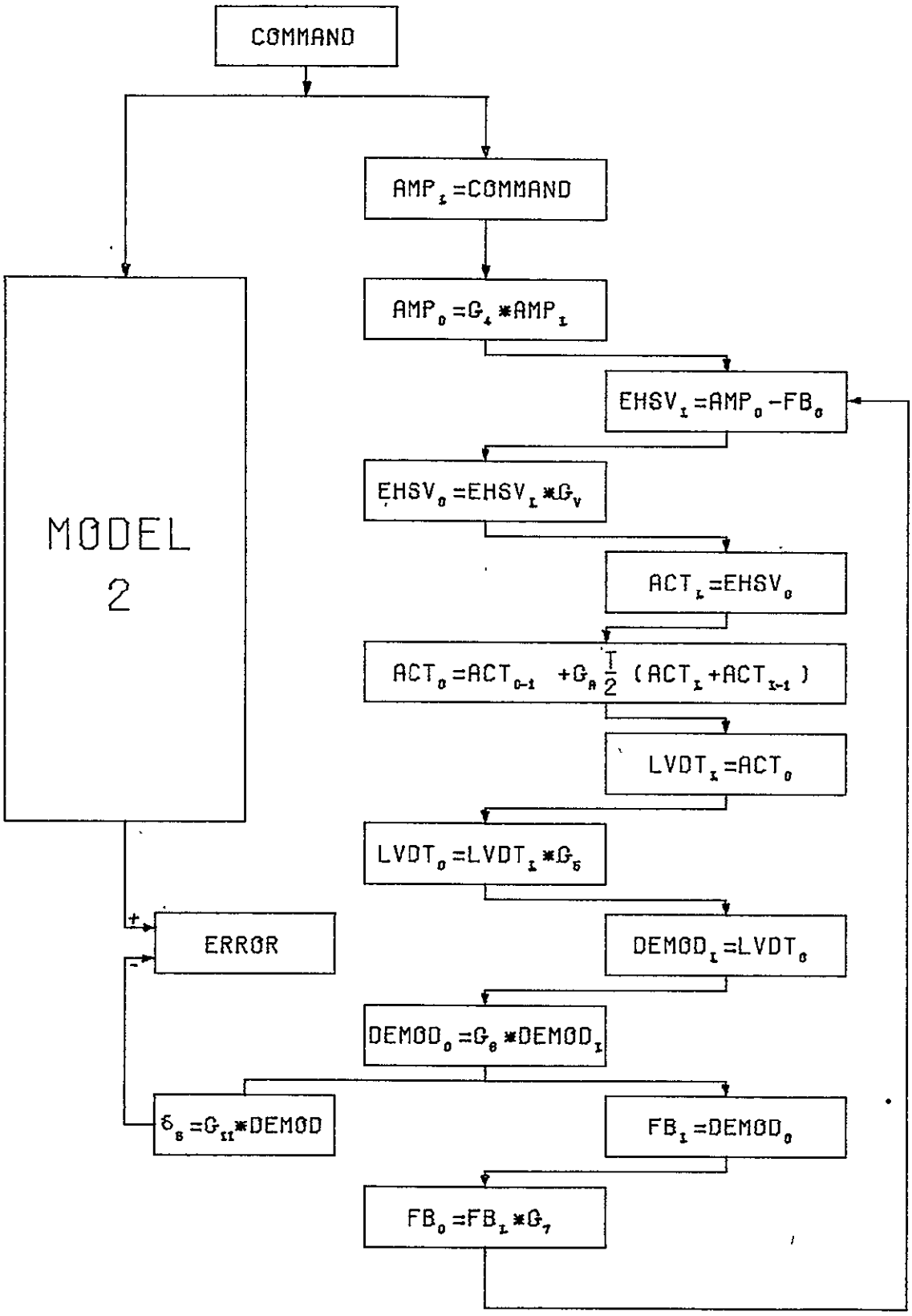


Figure 8.- Flowchart of the servosystem computer model and CSCM scheme.

error signal value (the input to the EHSV for the next iteration) was the difference between the command amplifier output and the feedback amplifier output (see figure 5). In the physical system the LVDT demodulator is reverse polarity with respect to the command signal. The FORTRAN model of the LVDT demodulator output had the same polarity as the command signal for convenient analysis.

The modeling of the CSCM technique was made up of two servosystem models to represent the canard control surfaces. This was designed to allow one servosystem model to have nominal gains according to table 3 and the other to be varied, for sensitivity test purposes. The resulting error between the two models was of interest in determining the effects of disproportionate servosystems. The same command value was applied to each servosystem. The output values of each LVDT demodulator block were converted to the equivalent control surface deflection. The first servosystem model corresponded to the right control surface. The error value between surfaces was the difference of the left surface from the right surface, where the left surface corresponded to the second model. The appendix contains a computer listing of the FORTRAN program. Figure 5 shows a block diagram of the servosystem and CSCM method.

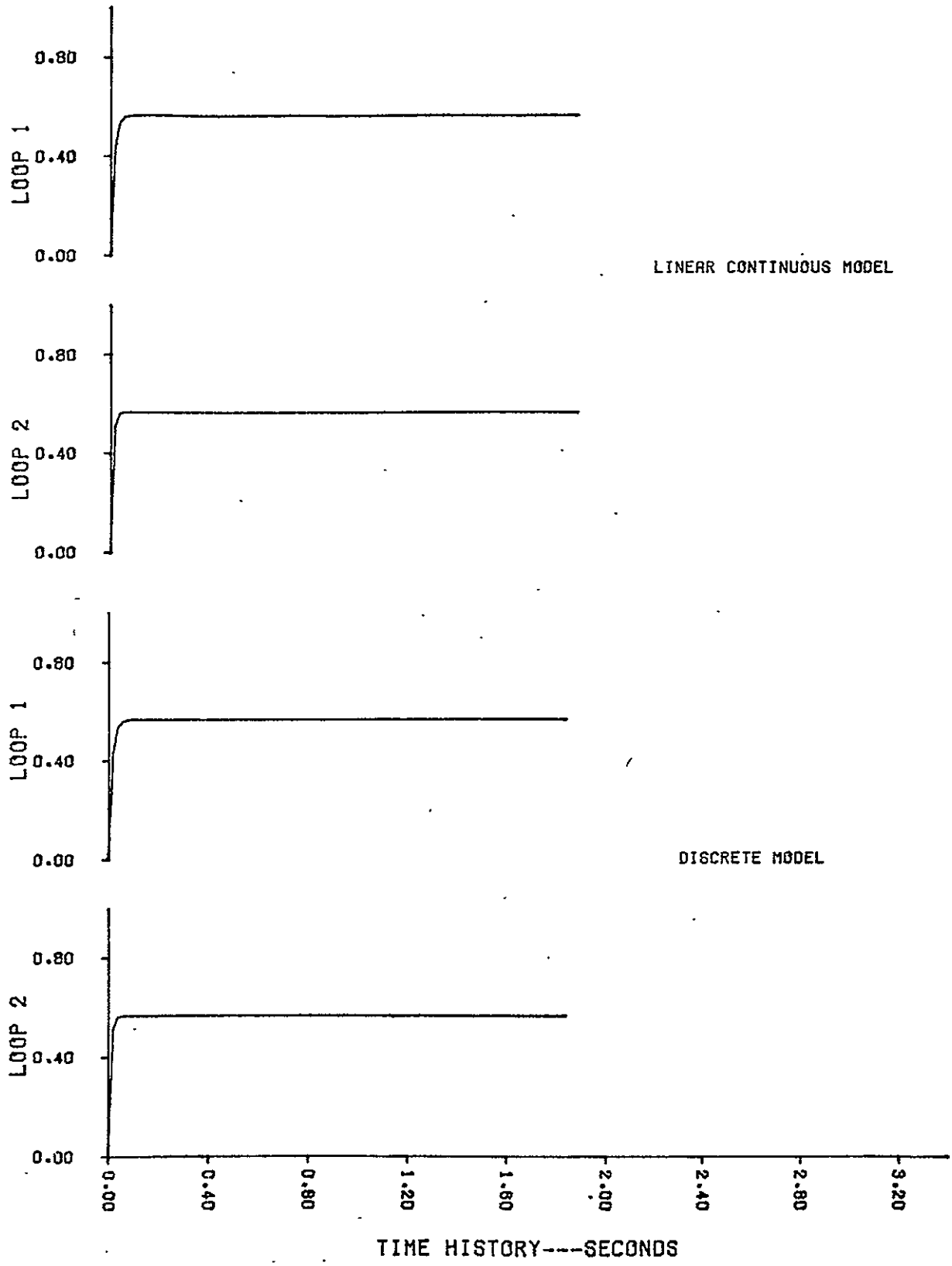
Simplifying assumptions. - A reasonable assumption concerning the frequency of the command input signal was that it would not be higher than 15 hertz. It follows that the EHSV, the LVDT and LVDT demodulator, and servoamplifier dynamics would cause negligible attenuation and phase shift. These

elements were modeled as pure gain elements. The actuator was conveniently modeled as an integrator and implemented in the digital program using the bilinear transformation expression (ref. 7,8). For the Kth iteration,

$$\text{output}_K = \text{output}_{K-1} + T/2\ (\text{input}_K + \text{input}_{K-1})$$

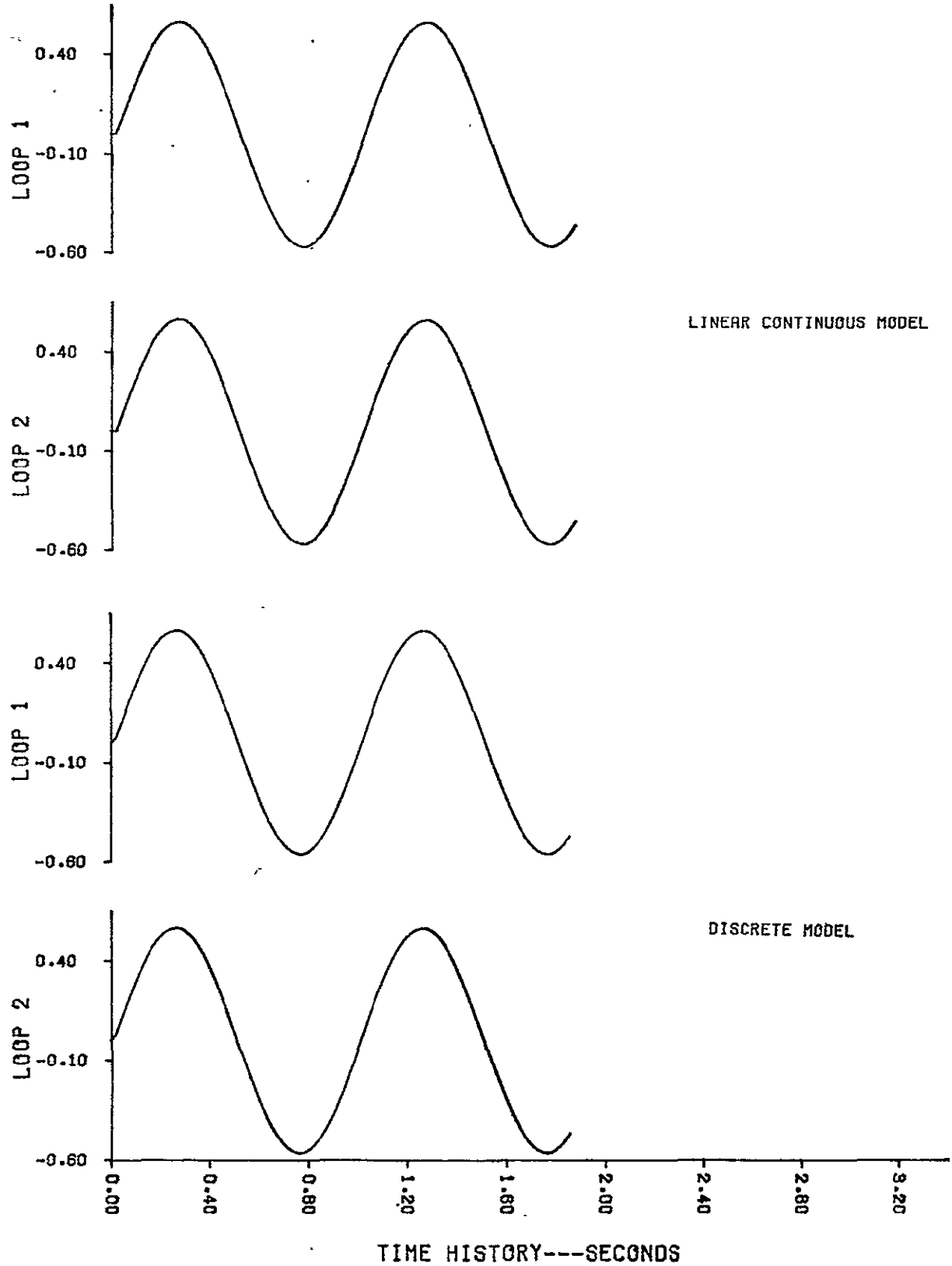
where T is the sample period, that is, the time between iterations and was nominally 0.2 milliseconds, 5000 hertz iteration rate. To obtain sufficient accuracy using the bilinear transformation expression for the integrator, the sample frequency was set much higher than the first-order pole of the model (greater by a factor of ten or more). The past input and output values were updated with each iteration.

Verification. - The CONTROL digital computer program (ref. 9), a program for analyzing linear continuous systems, was used to verify that the discrete model was an accurate representation of the linear first-order model of the simplex servosystem. Time history responses, of the control model and the discrete model, were compared. There was no detectable difference. The CSCM model was also verified by using two servosystem models in each program to simulate the CSCM. In both programs the difference of one servosystem monitor output from the other was computed to give an error value. The models corresponding to the right servosystem in each program had equal gains and the models corresponding to the left servosystems had equal gains but the right and left sides were unequal. As can be seen in figures 9a and 9b, for a step input and a sine wave input, the discrete model compares very close-



(a) Step input.

Figure 9.- Response of linear continuous models 1 and 2 and discrete models 1 and 2.



(b) Sine wave input.

Figure 9. Concluded.

ly to the linear continuous model.

Non-linear Model

The following subsection describes the non-linearities that were added to the linear model. T The origin of these non-linearities and the likelihood of any contribution to the error between unfailed actuators is discussed. The assumptions that were made in implementing these characteristics and the verification procedures are given.

Description. - The non-linearities that were added to the model are among the more common ones associated with servo-systems. The non-linear characteristics added were:

- EHSV current limiting
- EHSV threshold current
- Actuator ram position limit
- Total servosystem hysteresis

The EHSV provides the electrical-to-hydraulic interface which controls the source of fluid power to the hydraulic actuator. The EHSV rated current range changes the fluid flow, to the actuator, from maximum extension control flow to maximum retraction control flow. The servoamplifier supplies current to the EHSV within the specified range, plus or minus 4 milliampheres (ref. 3)

The EHSV threshold current non-linearity is essentially a characteristic produced by the static friction of the sliding valve. The specified threshold value was determined by the manufacturer during quality assurance tests. The current increment required to reverse the EHSV from a condition of increasing output was measured. The current was changed at a

a rate below that at which dynamic effects were important.

The actuator ram position limit is the maximum extension or retraction distance from the null position. For the CSCM model the full stroke (F.S.) of the actuator ram was approximately 2.56 cm (ref. 3). The position limits were plus and minus one half of this amount.

The actuator ram rate limit is the rate at which the ram can extend or retract under no-load conditions with maximum control flow from the EHSV. The rate limit is dependent on the properties of the other components in the loop. A change in loop gain may affect the rate limit as will a change in the maximum control flow from the EHSV. The current limit implementation was in effect a rate limit since a decrease in the current maximum output would decrease the control flow maximum output. The actuator ram rate limit used was 5.87 cm per second (ref. 3).

The total servosystem hysteresis is defined as the maximum difference in command voltages required to produce the same actuator ram position during a single cycling of the command voltage. This cycling is done below the rate at which dynamic effects are important. The hysteresis non-linear characteristicis produced by the combined effects of the EHSV threshold and electromagnetic characteristics, and the static friction of the actuator ram.

Simplifying assumptions. - There were some general assumptions made to simplify the implementation of the non linear discrete model. Although a non-linearity in the physical system may be a function of several variables, in the

discrete model each non-linearity was assumed to be only a function of the input to that non-linear block. The linear representation of each servosystem element was retained. For example, in implementing the EHSV current limit characteristic, the EHSV input value was tested to determine if it was greater than or less than the limit values. If so, it was set equal to the appropriate limit value. The expression for EHSV behavior was not affected, it remained a pure gain element.

It was assumed that the non-linearities would be closely approximated as ideal non-linearities. For example, the total hysteresis value, as measured, might not be uniform for the full stroke of the actuator ram in the physical system. It was assumed to be uniform for the non-linear implementation in the discrete model.

It was also assumed, for the discrete model, that because the EHSV threshold produces a hysteresis non-linearity in the closed-loop response, the total hysteresis could be modeled by adjusting the threshold value. The position limits were included in the model. A difference in the position limits would produce an error between surfaces only at the maximum deflections. This effect was not investigated. A difference in the current limits of the EHSV would amount to a difference in the rate limit, which was investigated.

Verification. - The current limiter, and position and rate limiters are shown in figures 10a and 10b, respectively. The 10 degree command sine wave is shown in figure 10a along with the resulting input current waveform of the EHSV which

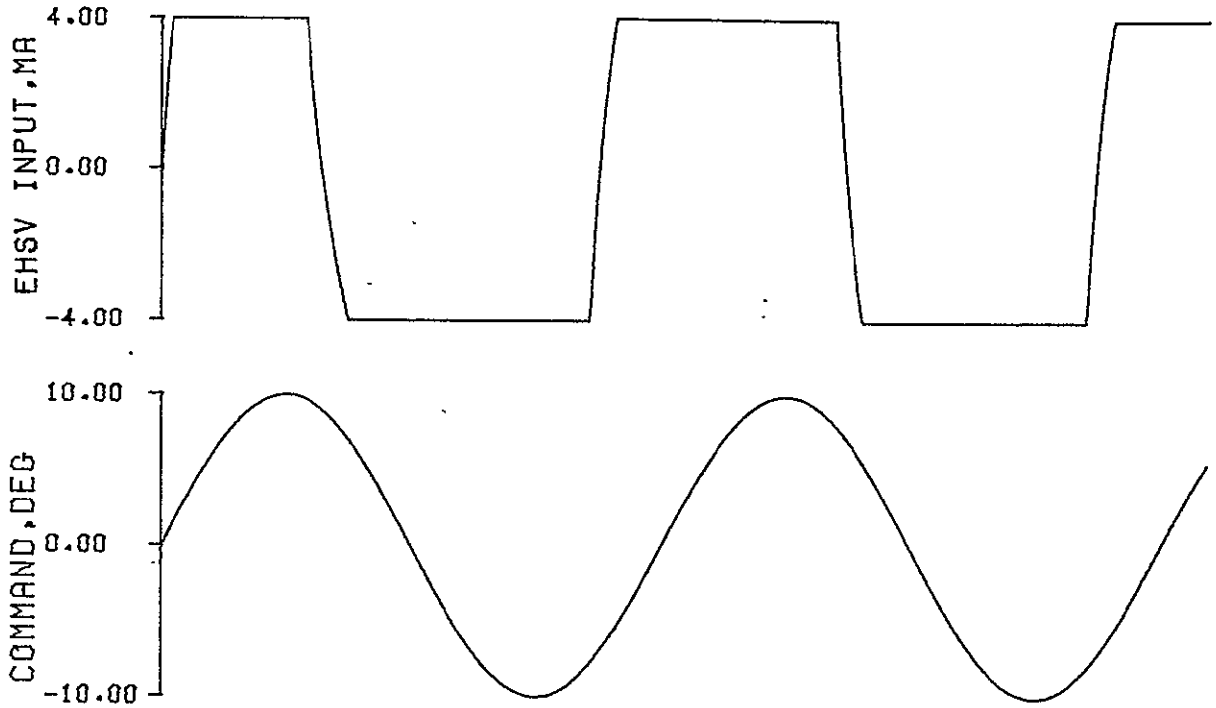


Figure 10a.- Output of the current limiter block for a 10-degree sine wave command.

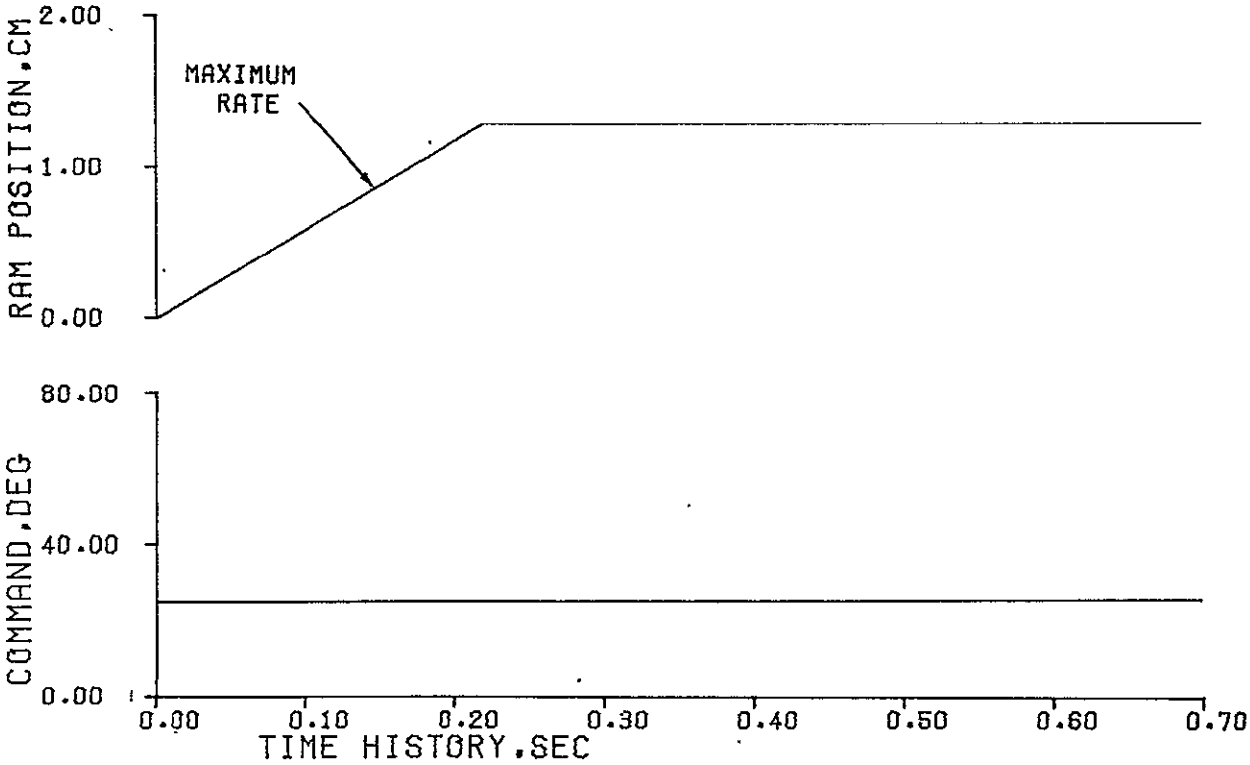


Figure 10b. Actuator response to a 25 degree step command illustrating rate and position limits.

was limited to plus or minus 4 milliamperes. Figure 10b shows the ram position and the maximum positive ram extension of 1.28 centimeters and also the maximum extension rate of 5.87 centimeters per second for a 25 degree step command. The threshold non-linearity is shown in figure 11 and hysteresis non-linearity, resulting from the closed loop response, is shown in figure 12. The horizontal axis is the input and the vertical axis is the output of the non-linear block. The non linear block diagram is shown in figure 13. The inputs labeled N_1 and N_2 are points where noise was introduced into the model.

COMPUTER ANALYSIS

The objectives and procedures for the parameter sensitivity test of the CSCM technique are given. This test uses the non-linear digital model described in the preceding section.

Objectives

There were five main objectives in testing the sensitivity of various parameters in the CSCM technique

1. Determine the sensitivity of the error between servosystem LVDT demodulator outputs to variations in the values of the threshold and rate limit non-linearities.

2. Determine the effect of loop gain differences on the error between servosystems.

3. Investigate the effect typical system noise may have on the error between servosystems.

4. Investigate the demodulator ripple, sampling time difference, and digital-to-analog and analog-to-digital conversion errors.

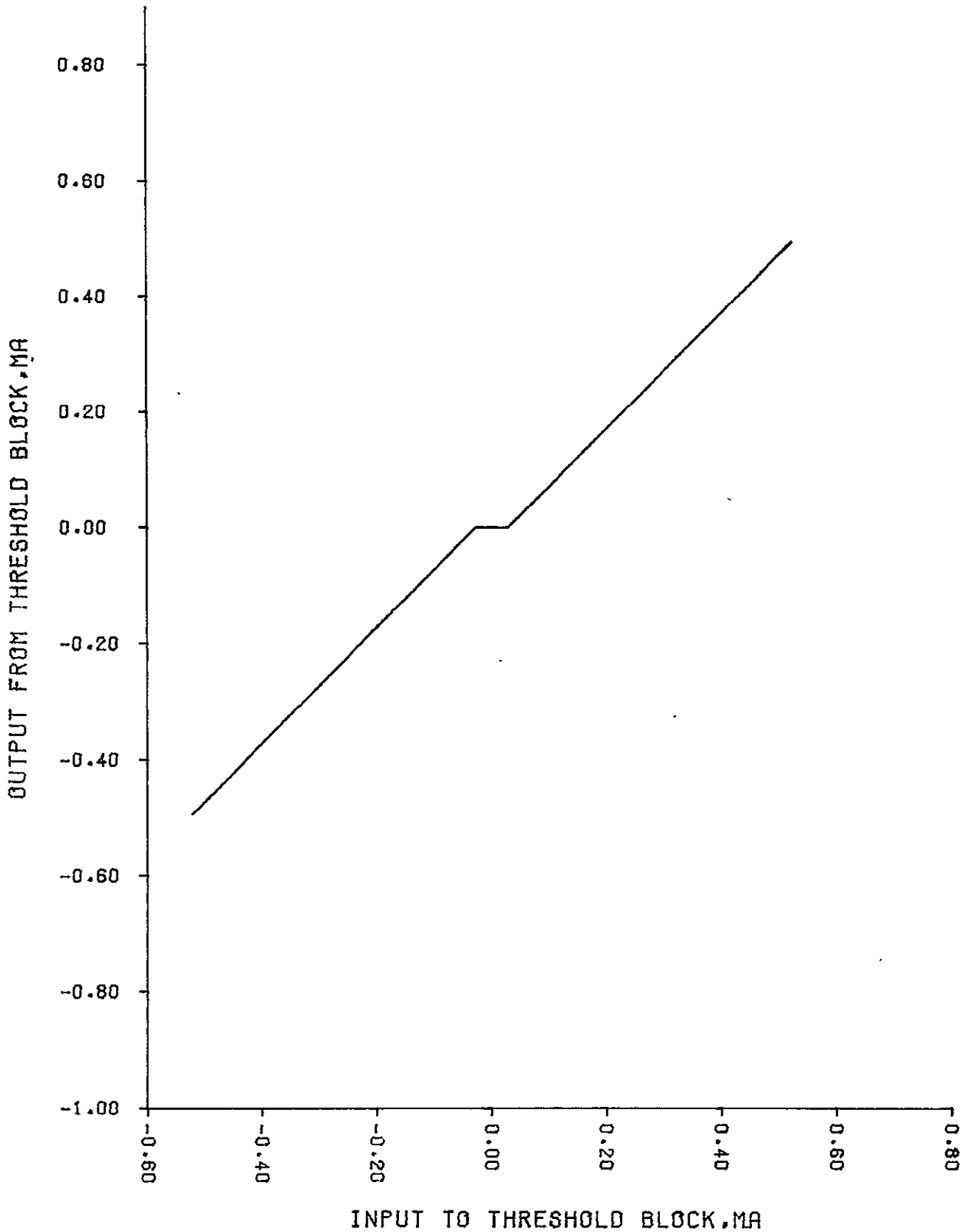


Figure 11.- Threshold nonlinear block characteristics.

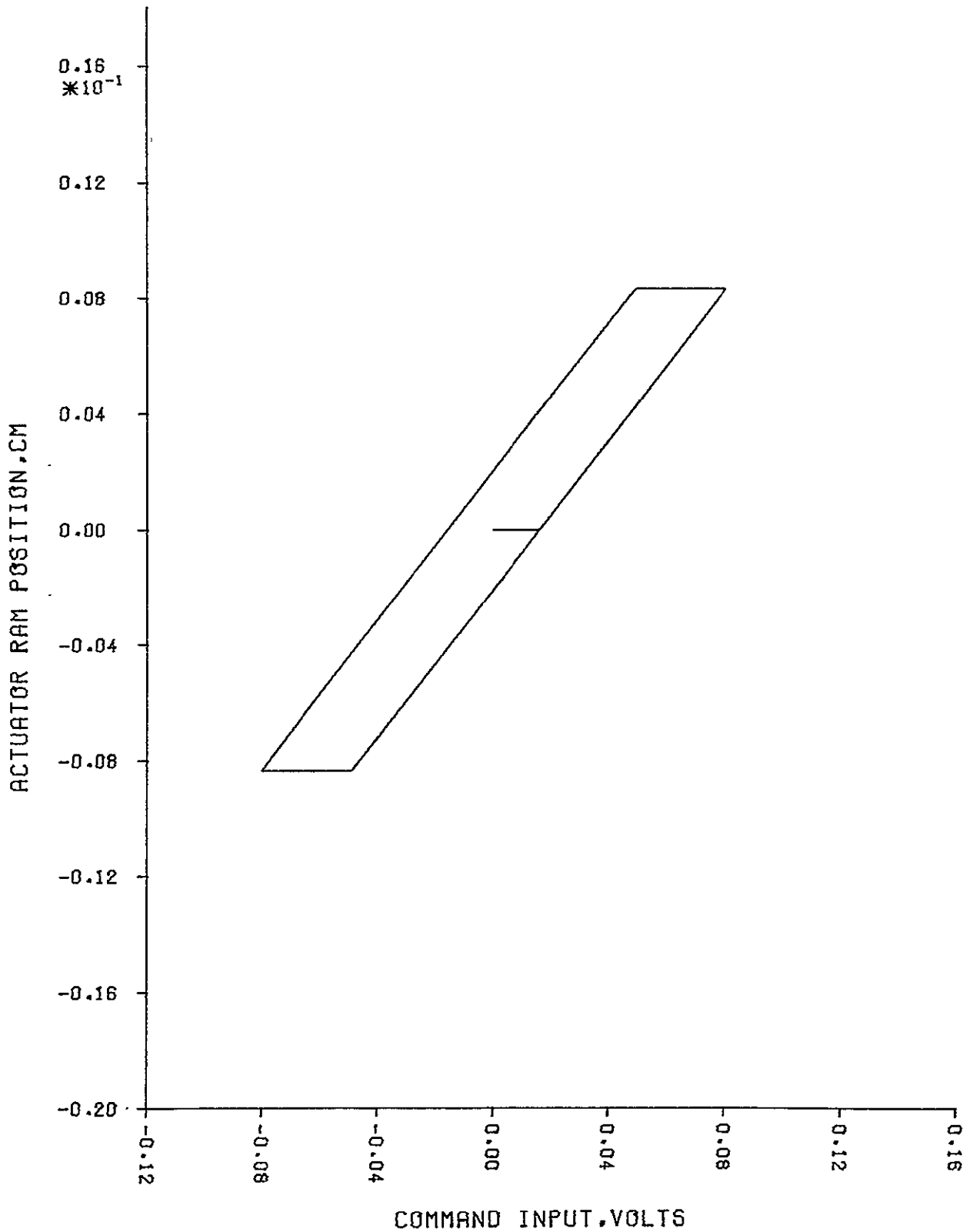


Figure 12.- Hysteresis nonlinear block characteristics.

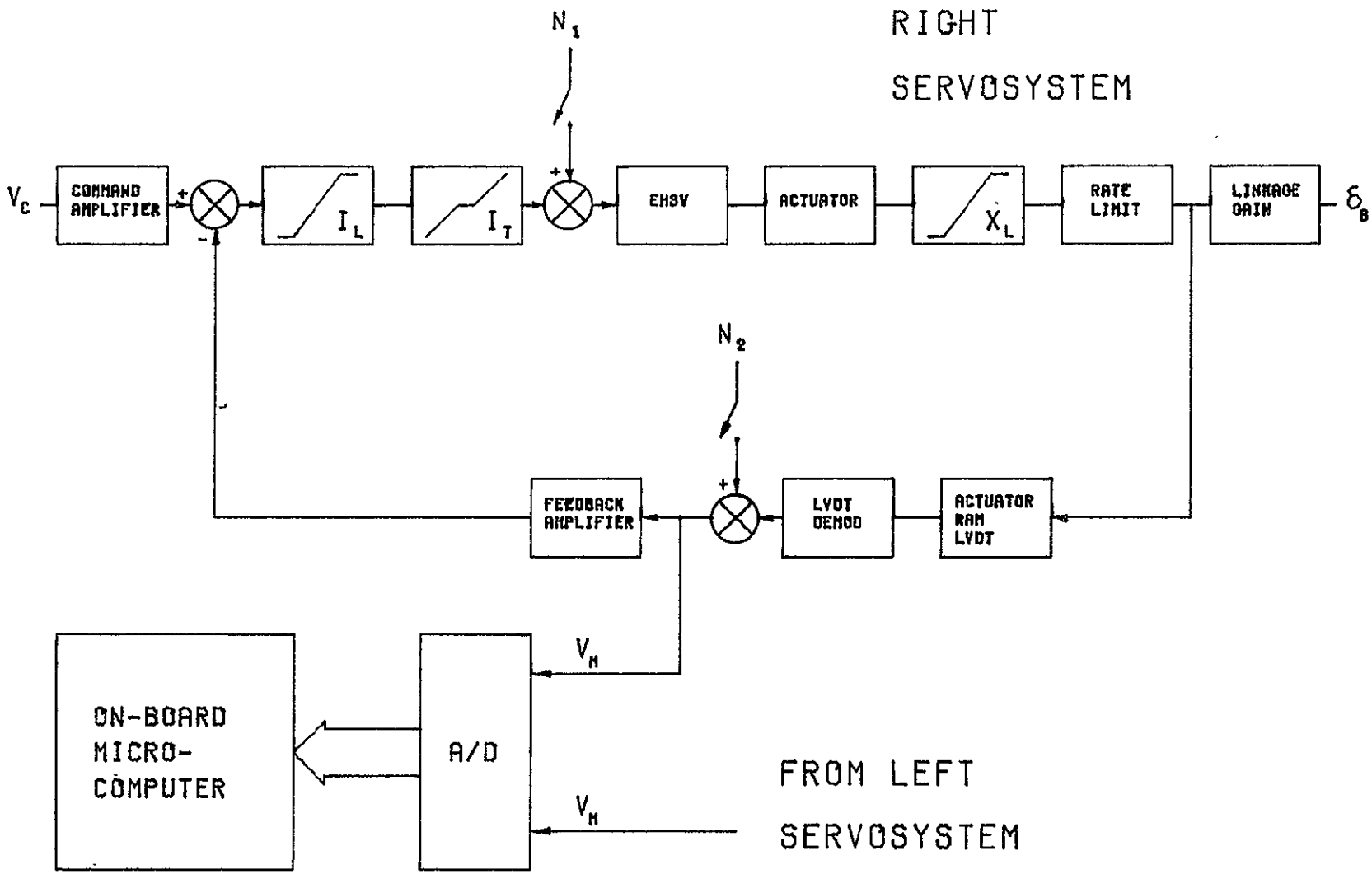


Figure 13.- Block diagram of the servosystem model and CSCM scheme including nonlinear blocks.

5. Determine the total effect on the error value for two servosystems with reasonable differences in characteristics.

Using the data from the tests a judgement was made as to the impact of nonidentical servosystems on the performance of the CSCM failure detection technique. Potential solutions to problems that were evident were then formulated.

Test Procedure

The test objectives were met by varying the parameters of interest and collecting data on the response of the CSCM error value. The input command for each case was a six degree step command, a somewhat severe command but appropriate for the test.

Loop gain variations. - In order to study the effect of loop gain differences the gains of the left servosystem elements were set to the nominal values (see table 3). The right servosystem loop gain was theh changed for each case by changing the dc gain of the actuator. The difference between the two servosystem gains would most likely be less than six percent. This is because the design specifications cite an overall system gain accuracy of plus or minus three precent for the test. The right servosystem loop gain was varied from 80 percent to 120 percent of the nominal value in five percent increments. The error magnitude, in degrees, for a step input is shown in figure 14. Notice that for the higher than nominal loop gains the error was zero for a time. This is due to the fact that the rate limiter was holding both actuator rates equal. Only when the actuators came off the rate limit was

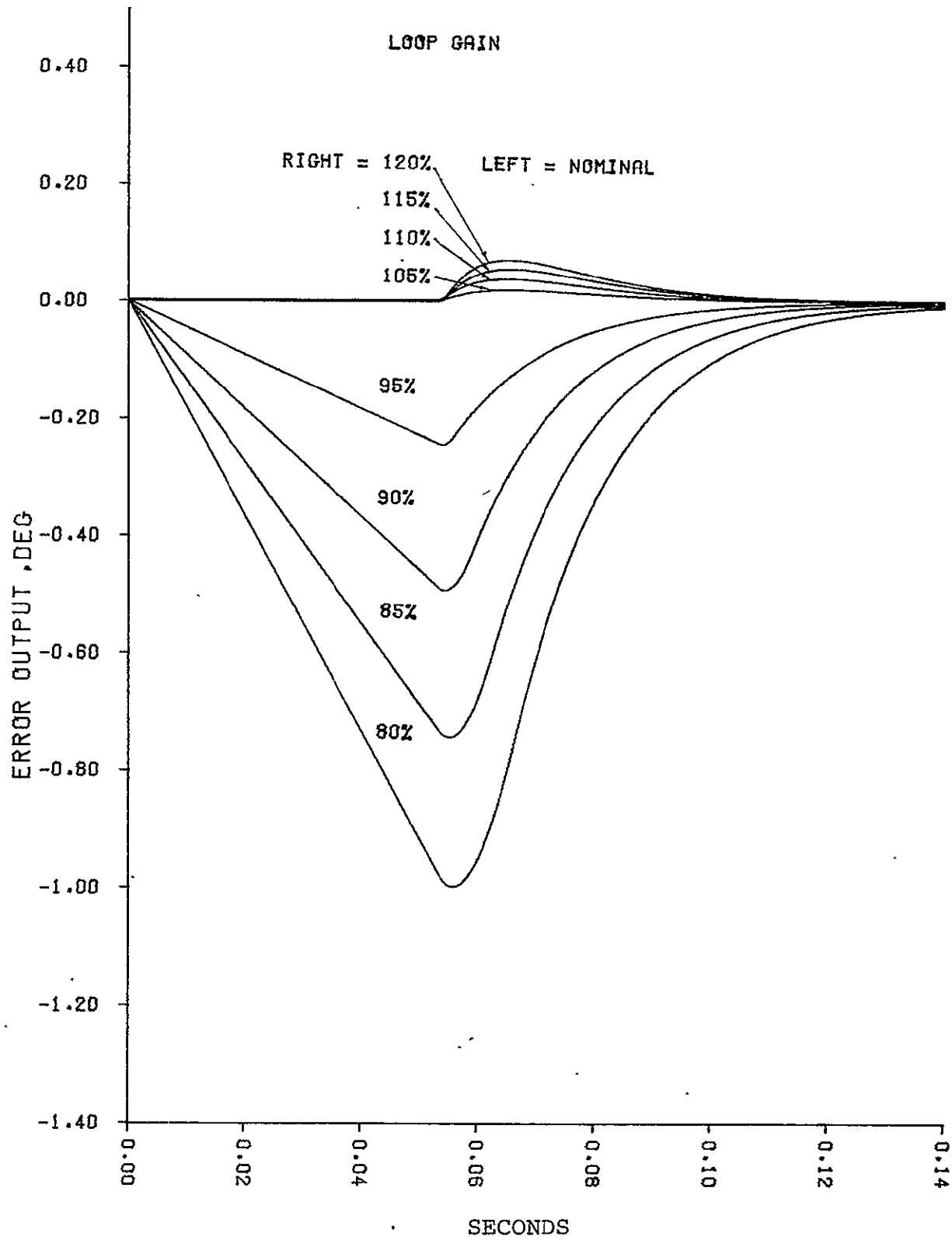
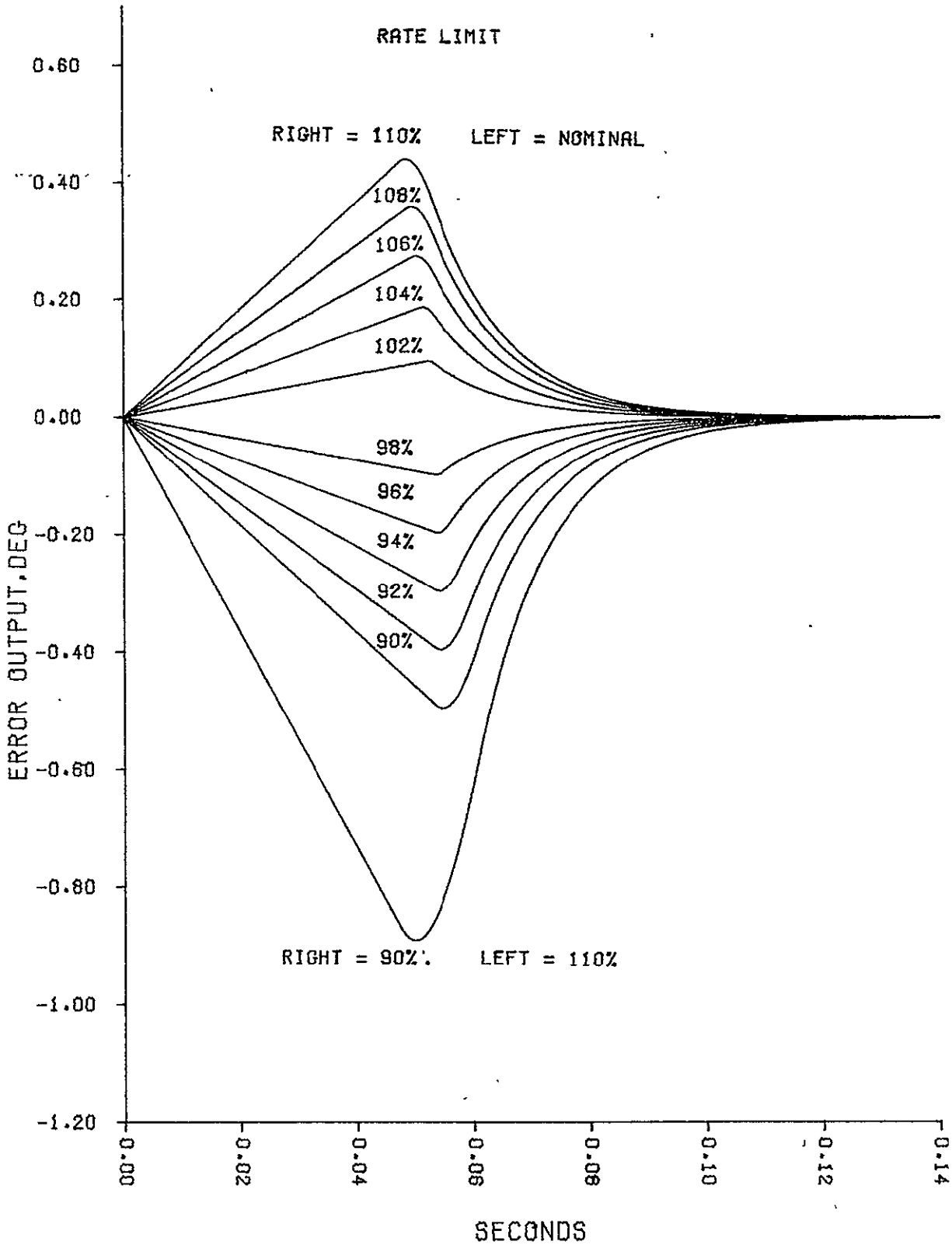


Figure 14.- Error curves resulting from loop gain differences.

an error seen. For cases where the loop gain of the right servosystem is less than the nominal value, the rate limit is less than nominal. Therefore, the error varies according to the difference between rate limits.

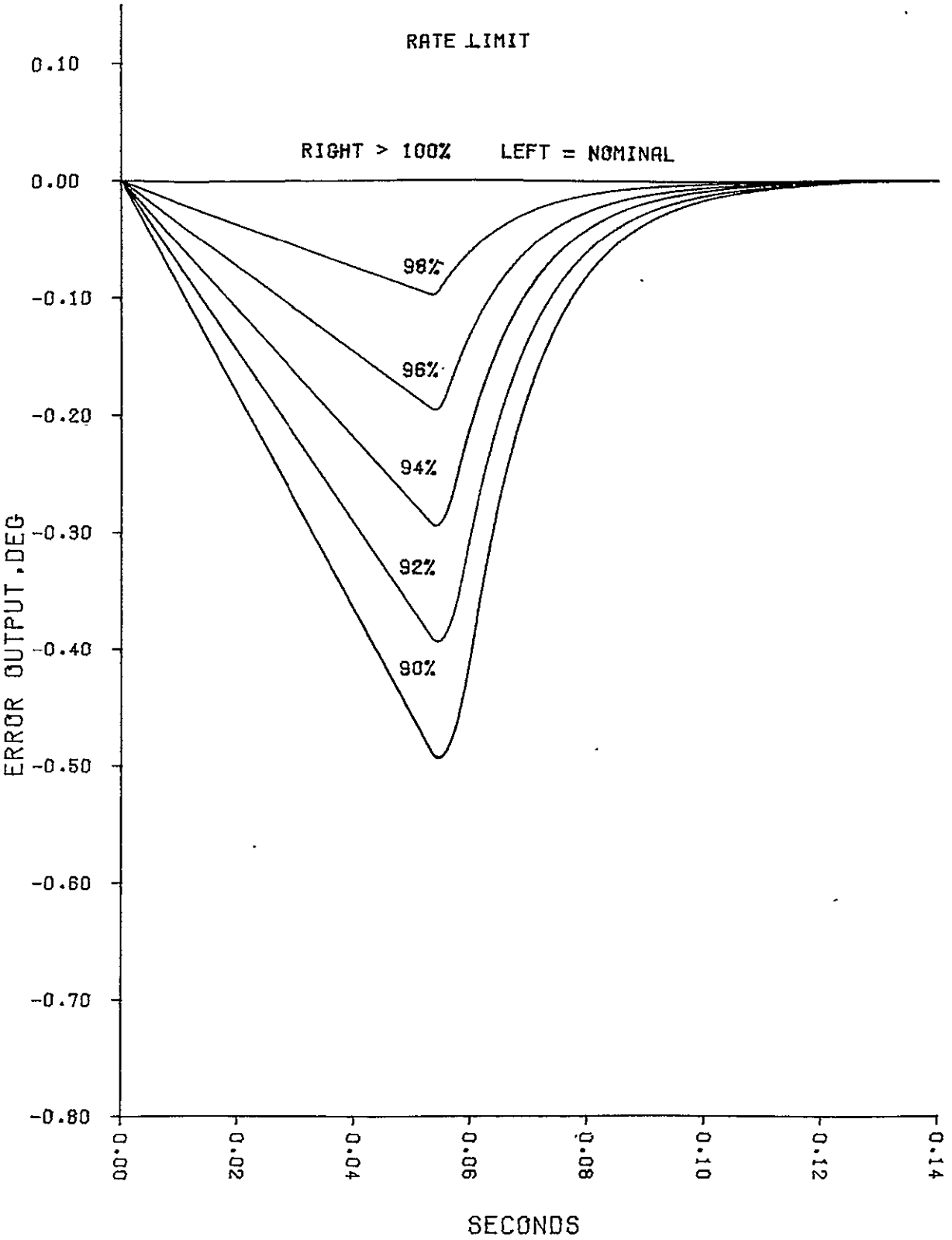
Rate limit variations. - The rate limit of the left servosystem model was held at the nominal specification while the right servosystem model had a rate limit variation from 90 percent to 110 percent in two percent increments. For one case, the left servosystem was set at 110 percent while the right servosystem was set at 90 percent of the nominal specifications. The eleven cases are shown in figure 15a. The current limiter was excluded to allow excursions of the rate limit beyond that fixed by the current limiter. When the current limiter was included there was no error. The right servosystem rate limit was set higher because the EHSV current limit was already limiting the rate to the nominal value in both servosystems. Figure 15b illustrates the result of the same test cases with the current limits included.

EHSV threshold and total hysteresis. - The design specifications for the simplex servosystems give an EHSV threshold value and a total servosystem hysteresis value, 0.7 percent and 0.15 percent of full stroke (F.S.), respectively. In the servosystem model, the EHSV threshold non-linearity implementation gives the hysteresis characteristic in the closed-loop response. One set of cases was run using the EHSV threshold specification for the left servosystem and varying the threshold value of the right servosystem in integral amounts up to ten times the nominal value. This set of cases



(a) Current limit block excluded.

Figure 15.- Error curves resulting from rate limit differences.



(b) Current limit block included.

Figure 15.- Concluded.

is shown in figure 16a. Again, there was no error until both servosystem models came off the rate limiters.

In order to model the total hysteresis, the threshold value of the EHSV was set to give the nominal hysteresis value for the left servosystem while the right servosystem was varied in integral amounts up to ten times the nominal value. Figure 16b shows the test results for a six degree step input.

Servosystem noise. - The effect of various types of noise on the error between servosystem models was investigated using a software pseudo-random noise generator. The noise signal was introduced at the EHSV input and at the demodulator output. Two cases using a different level of noise in each case were run for both noise input points. For the EHSV input, the noise level in each case was 0.1 percent of the maximum signal input (4.0 mA) and 3.0 percent of the maximum signal input. This is shown in figure 17a and 17b, respectively. For the demodulator output, the noise level in each case was 0.1 percent and 3.0 percent of the maximum demodulator output (5.61 Vdc) as shown in figure 17c, and 17d, respectively. The sampled values of the output were shown in these cases illustrating the values the on-board computer would be operating on.

Combined effects. - The combined effects of the previous sources of differences between servosystems were investigated. The left servosystem was set to the nominal specifications and the right servosystem characteristics were as shown in table 5. The resulting test plots are shown in Figure 18a-d.

Ripple error and sampling time differences. - For these test cases the demodulator ripple is added to the dc voltage

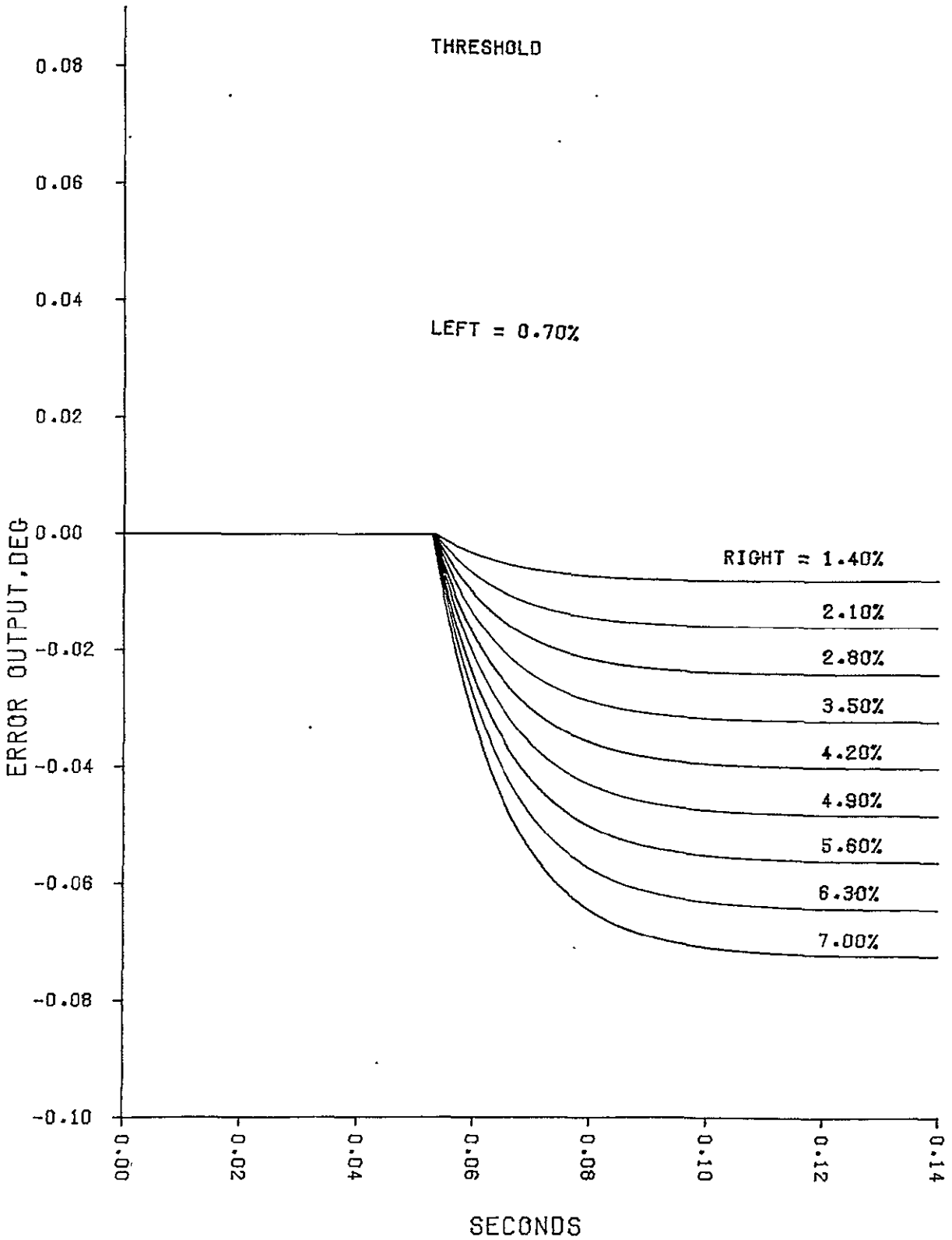


Figure 16a. Error curves resulting from EHSV threshold differences.

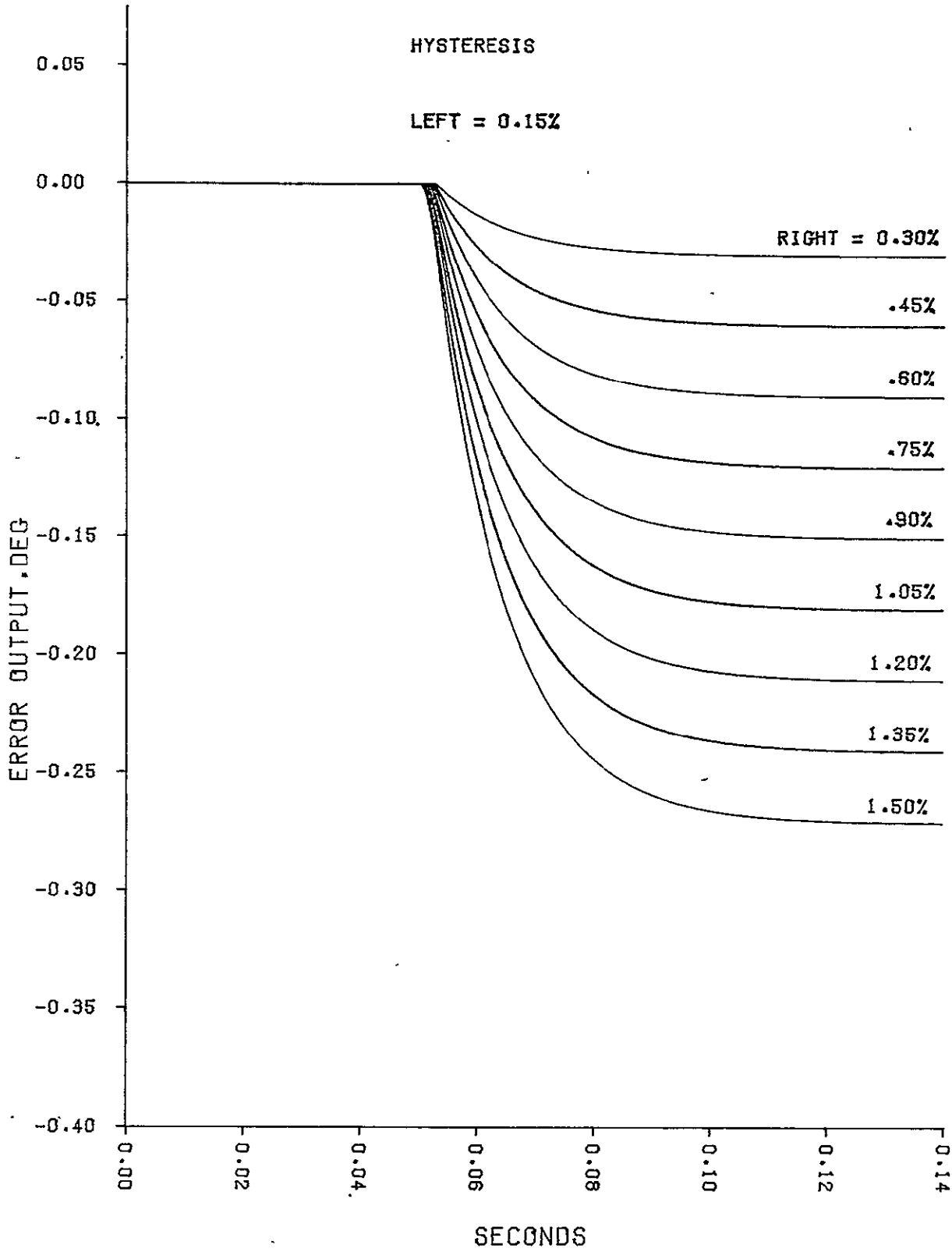
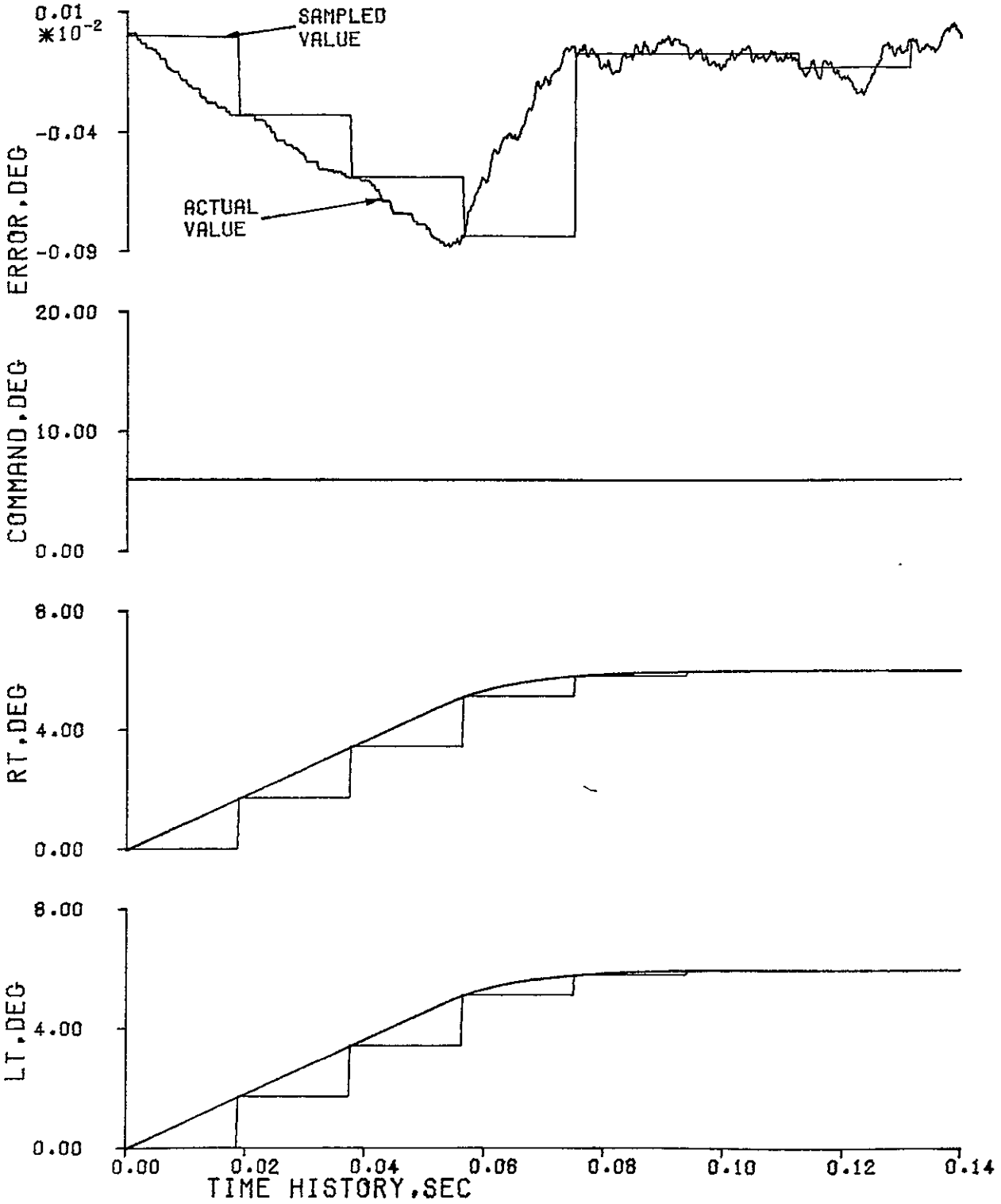
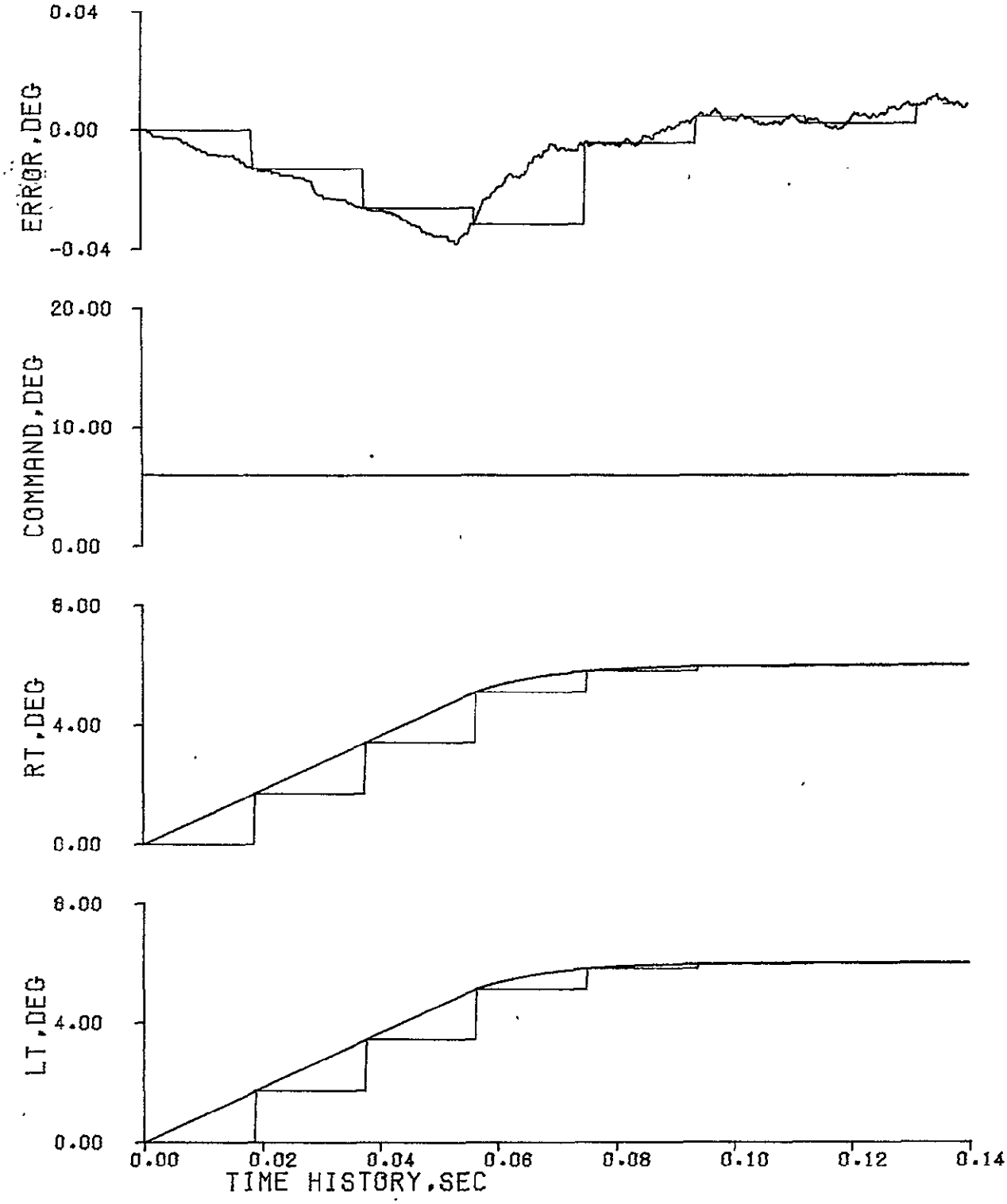


Figure 16b. Error curve resulting from total servosystem hysteresis difference.



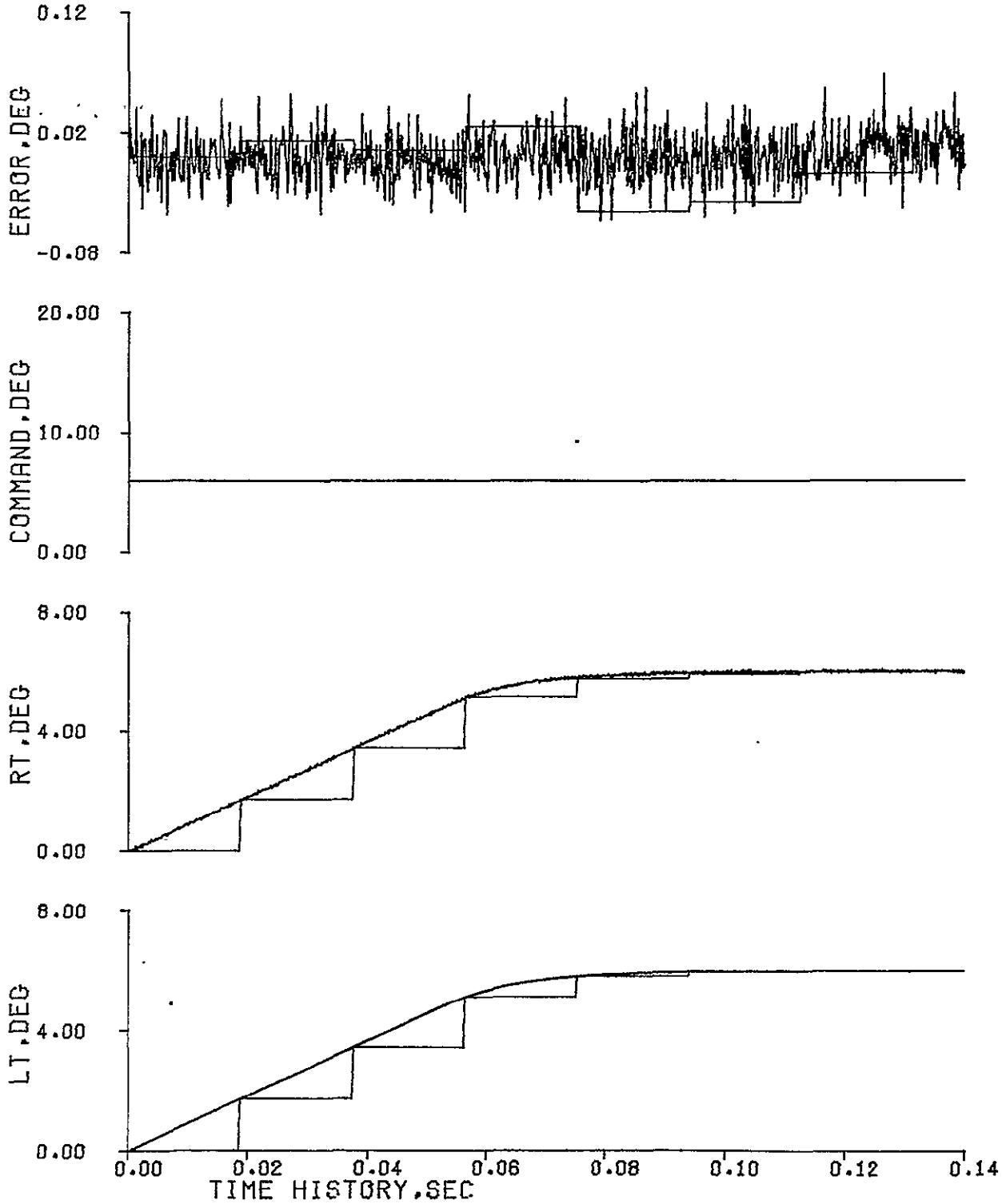
(a) Noise signal of 0.1% introduced at the EHSV input.

Figure 17.- Surface responses and monitor error for a step command.



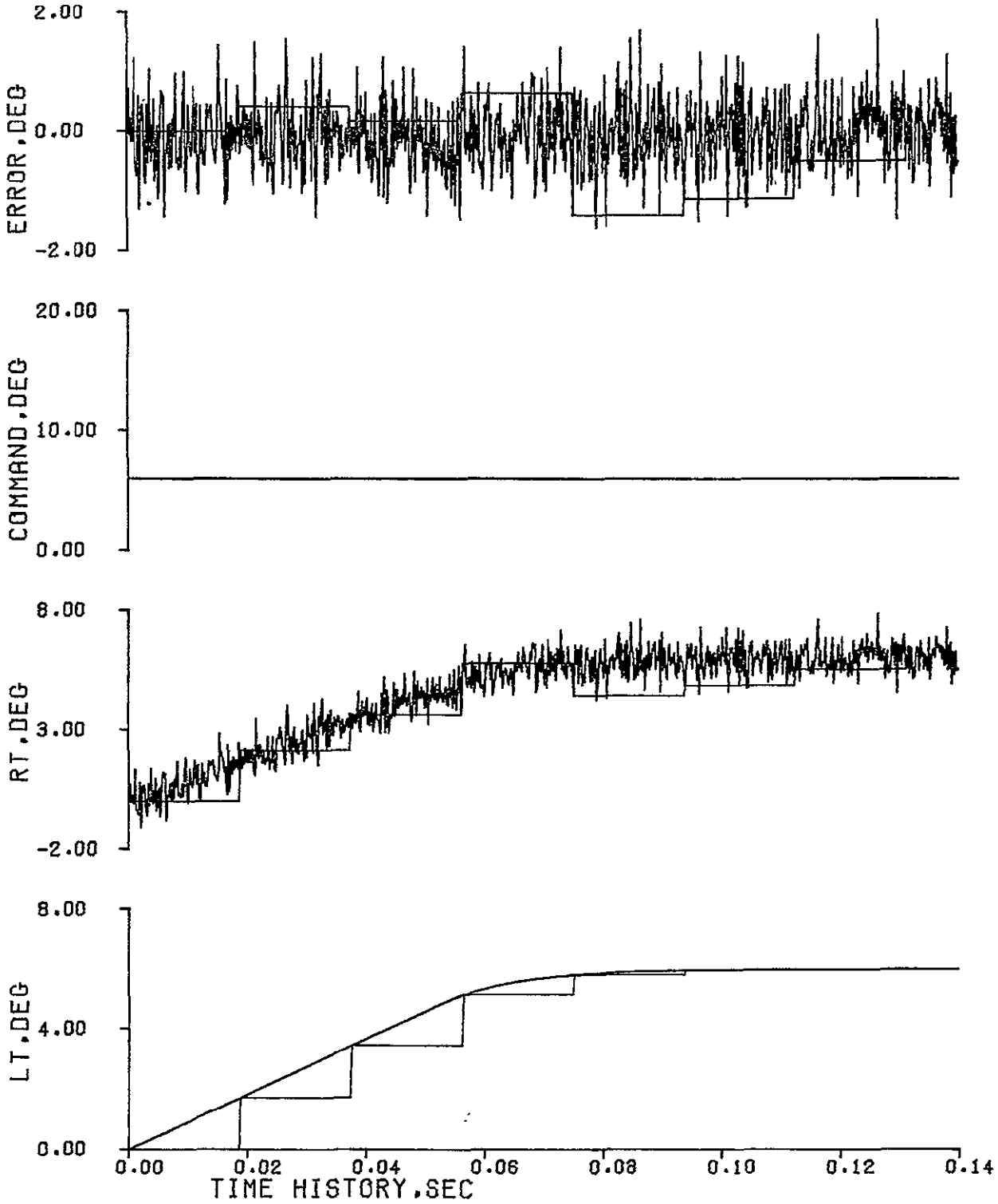
(b) Noise signals of 3.0% introduced at the EHSV input.

Figure 17.- Continued.



(c) Noise signal of 0.1% introduced at the demodulator input.

Figure 17.- Continued.



(d) Noise signal of 3.0% introduced at the demodulator output.

Figure 17.- Concluded.

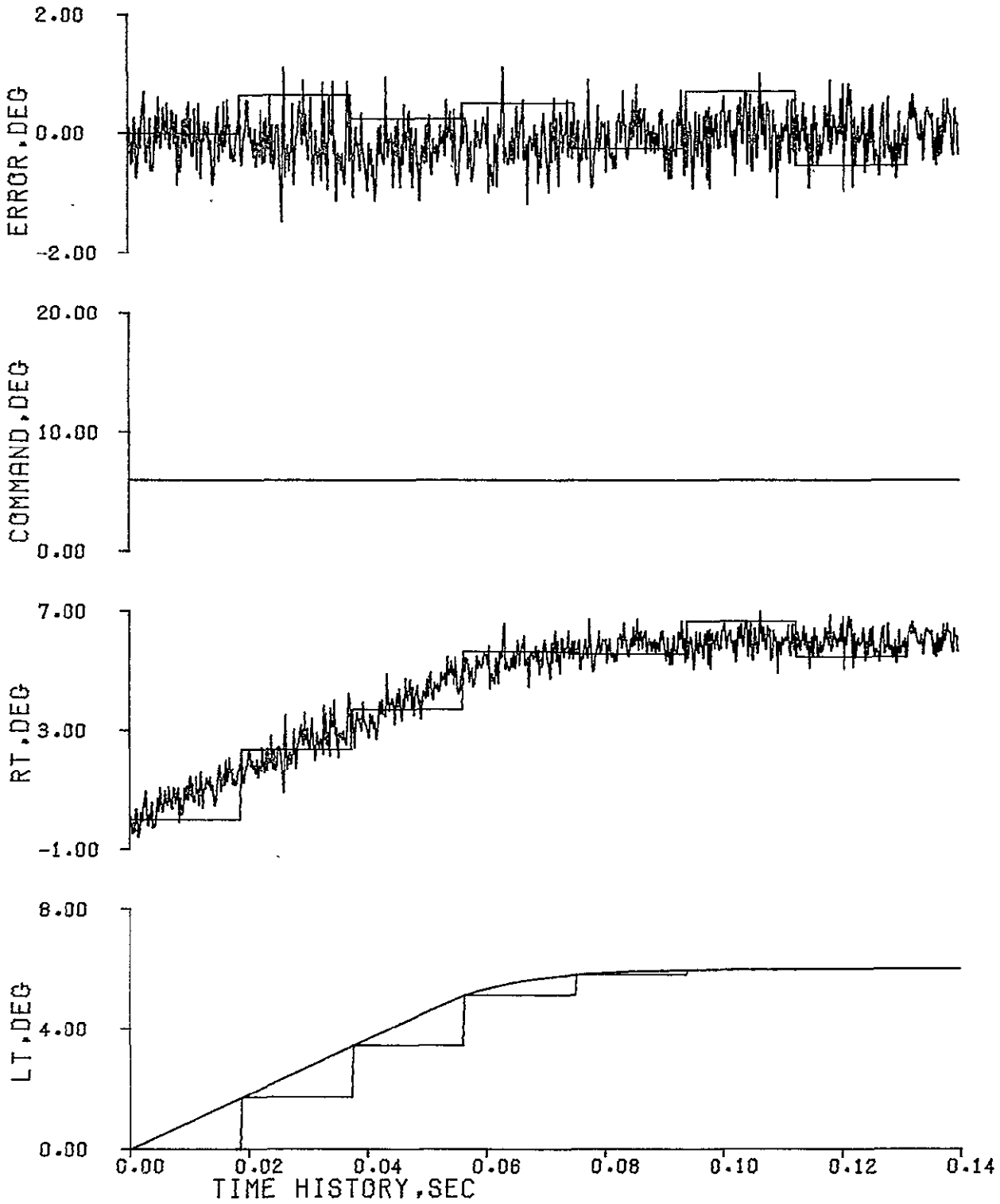
	RIGHT SERVOSYSTEM			
	CASE 1	CASE 2	CASE 3	CASE 4
Loop gain	97%	99%	97%	99%
Rate limit	95%	99%	95%	99%
Threshold	95%	99%	95%	99%
Hysteresis	95%	99%	95%	99%
EHSV input noise demodulator	2%	1%	-	-
Output noise	2%	1%	-	-

LEFT SERVOSYSTEM	
	CASE 1-4
Loop gain	80
Rate limit	5.87 cm/sec
Threshold	0.7% of F.S.
Hysteresis	0.04% of F.S.
EHSV input noise	-
Demodulator output noise	-

TABLE 5

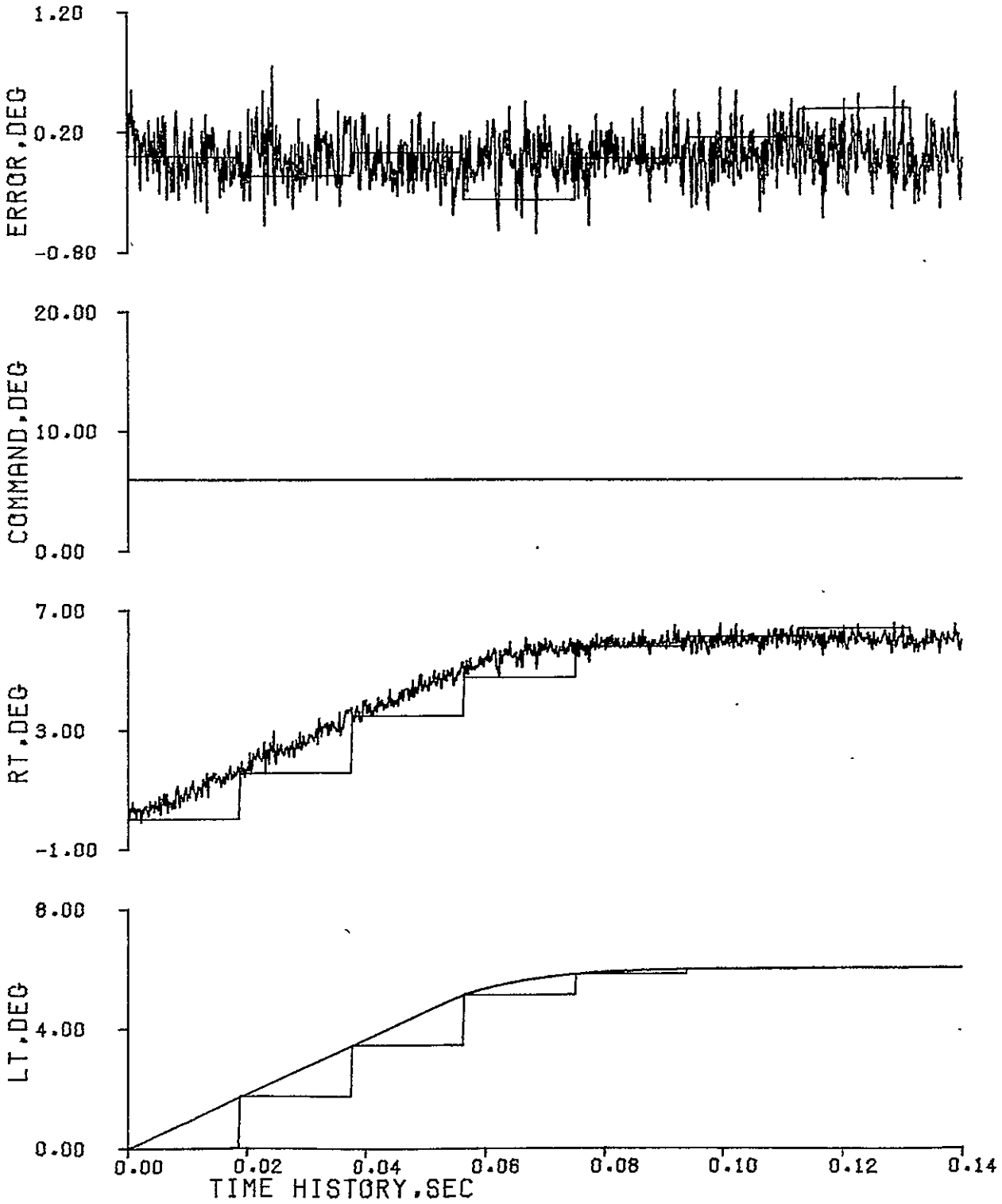
SUMMARY OF SERVOSYSTEM CONDITIONS FOR

INVESTIGATION OF COMBINED SERVOSYSTEM DIFFERENCES



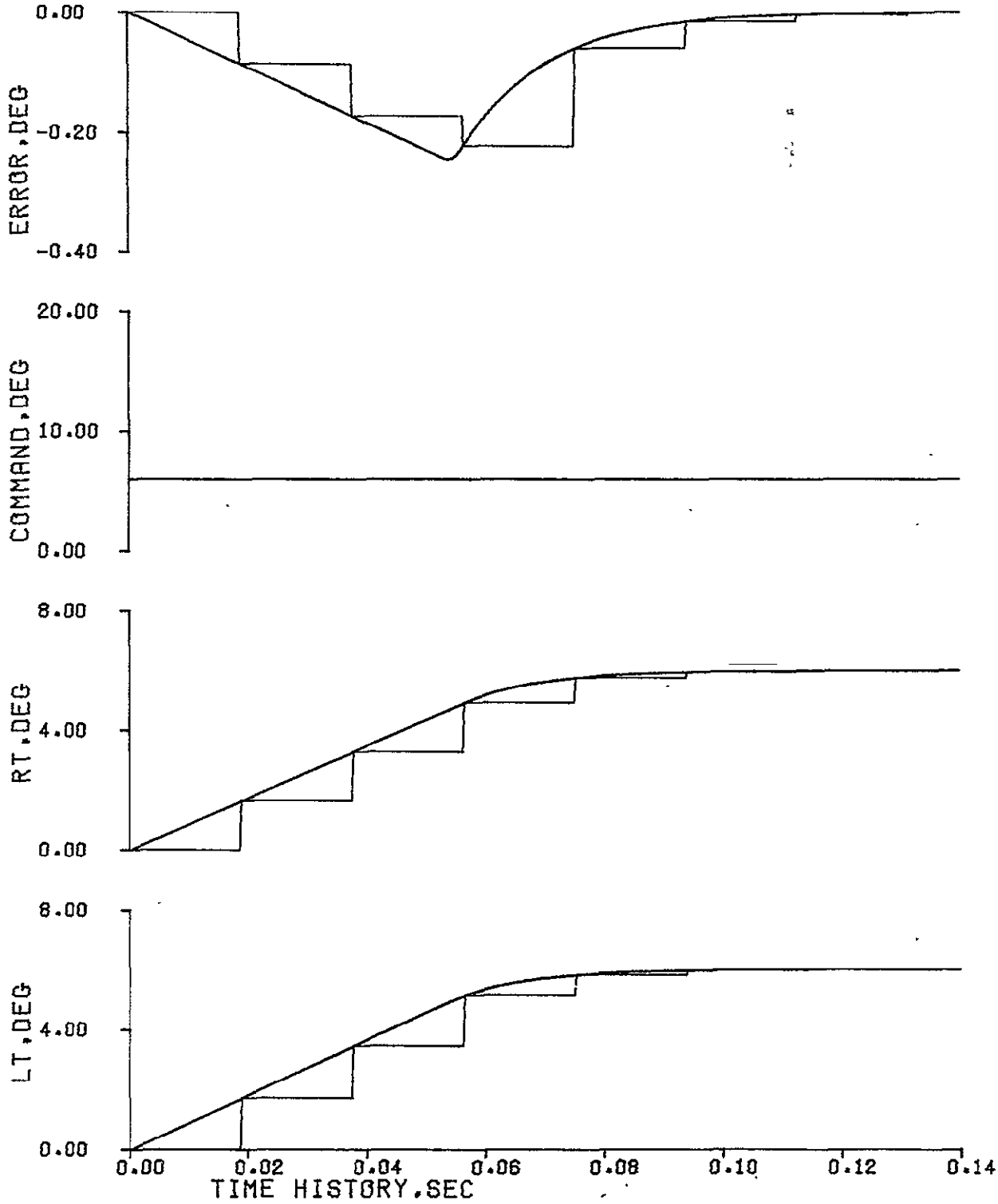
(a) Servosystem conditions as specified in case 1 of table 5.

Figure 18.- Surface responses and monitor error for a step command.



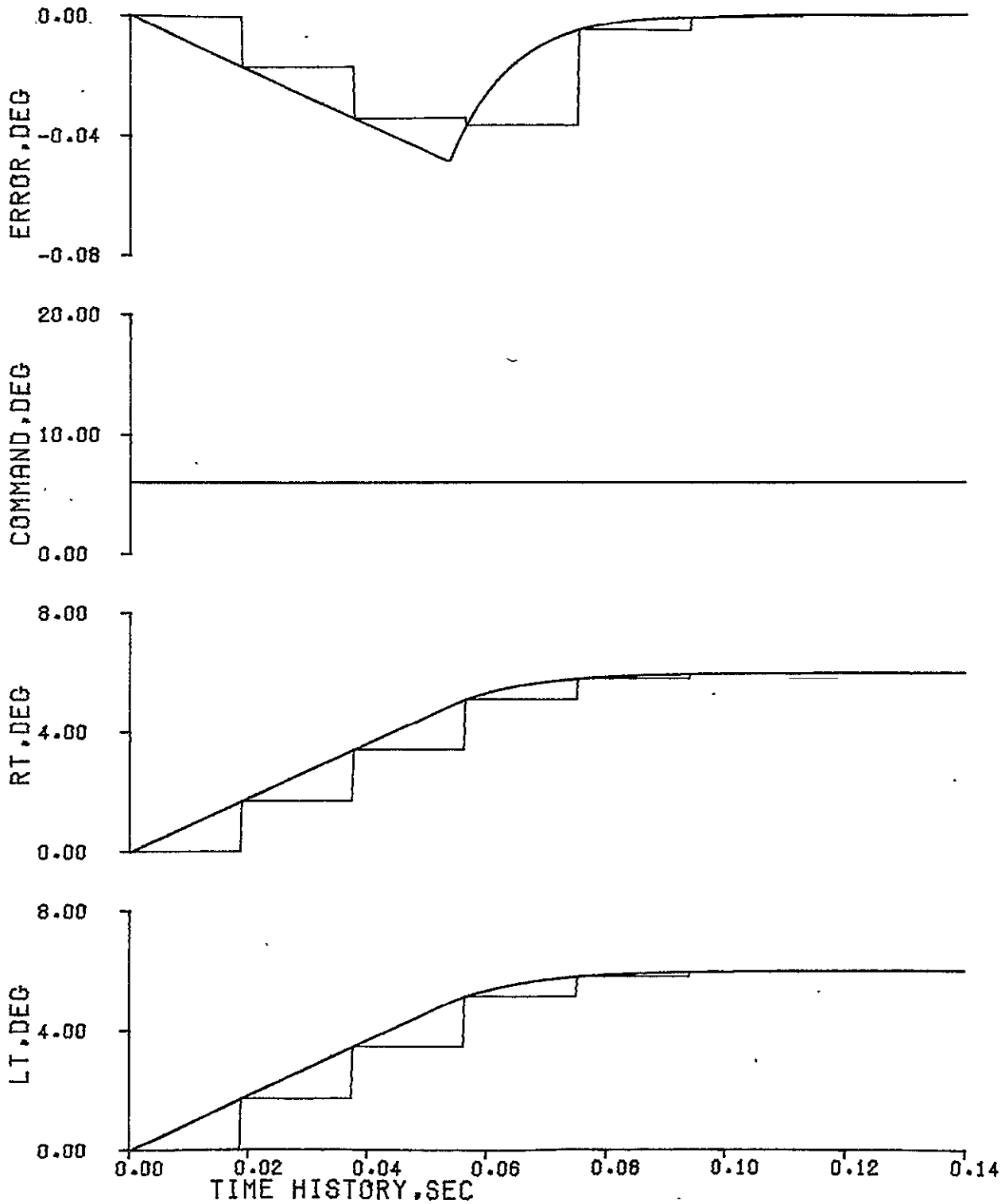
(b) Servosystem conditions as specified in case 2 of table 5.

Figure 18.- Continued.



(c) Servosystem conditions as specified in case 3 of table 5.

Figure 18.- Continued.



(d) Servosystem conditions as specified in case 4 of table 5.

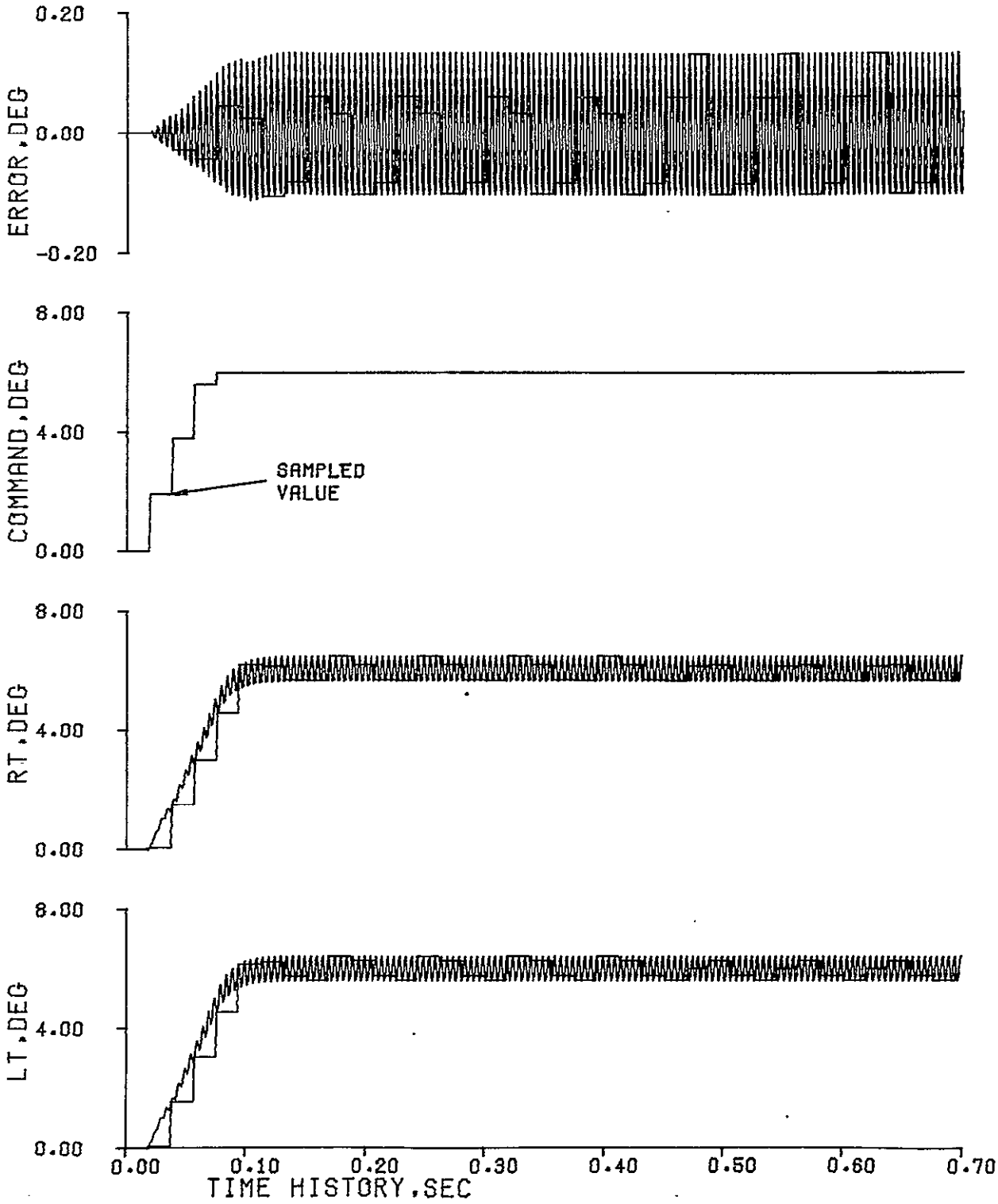
Figure 18.- Concluded.

output according to equations 1. To simulate this sampling time difference in the CSCM model, the ripple signals for each side are set out of phase by 16.2 degrees. The input command signal is a series of step inputs held to the command input rate limit of 100 degrees per second and with a final value of six degrees. The demodulator output samples are shown along with the actual waveform. The symmetric case is shown in figure 19a and the antisymmetric case is shown in figure 19b. The ripple waveform shown has a much lower frequency (ninth harmonic) because of the iteration rate (1000 sps). It serves to illustrate the amplitude, however.

COMPUTER ANALYSIS RESULTS AND DISCUSSION

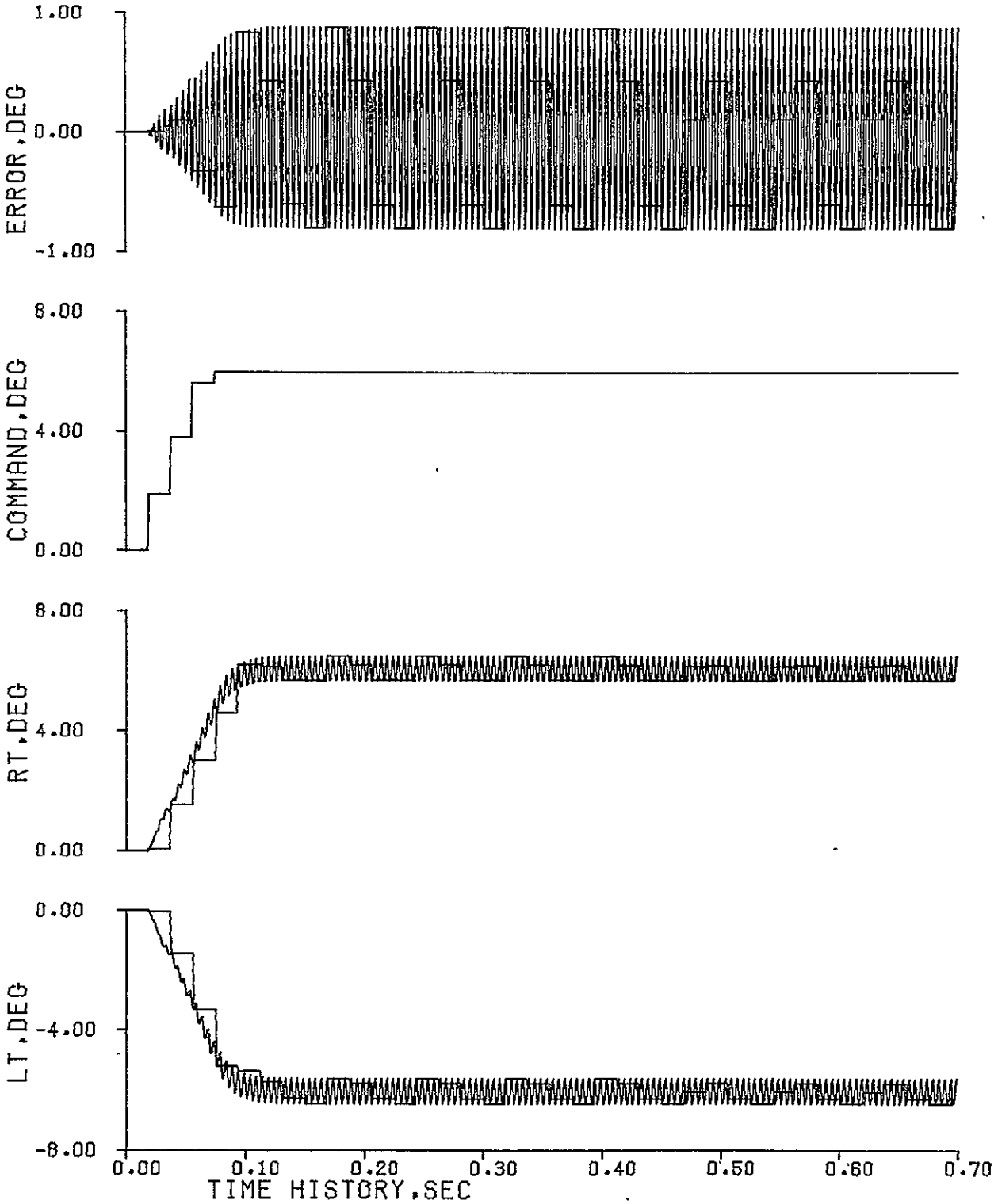
The computer analysis provided information as to the relative contribution of the possible error sources (loop gain, rate limit, threshold and hysteresis, system noise, and demodulator ripple) to the amount of detected error between servosystem position monitors. The error magnitudes, for test cases with varying differences between right and left servosystems (as shown in table 5), provides an estimate of the integrity of the CSCM failure detection method. That is, the likelihood of nuisance trips, for the computer threshold limits of table 4, may be hypothesized.

The loop gain variations shown in figure 14 indicate that the worst-case difference of six percent would contribute a peak value of approximately 0.3 degrees to the error. For the canard threshold limit of 3.65 degrees (assuming a maximum of 90 degrees per second error rate), this error would not contribute significantly to the likelihood of a nuisance trip. For



(a) Ripple signal added to the demodulator output of symmetrically moving surfaces.

Figure 19.- Surface responses and monitor error for a step command.



(b) Ripple signal added to the demodulator output of antisymmetrically moving surfaces.

Figure 19.- Concluded.

the aileron and elevator threshold limits of 0.65 and 0.69 degrees, respectively, a 0.3 degree contribution to the error value would increase the likelihood of a nuisance trip considerably. The loop gains should be matched as closely as possible to minimize this error contribution.

A difference between servosystem rate limits has the same effect, on the error value, as does differences in loop gains. Figure 15a and 15b illustrate the type of error response for a six degree step command. The maximum rate is dependent on the loading of the hydraulic actuator, in the physical system. For asymmetric aerodynamic loading on the control surfaces, the computer analysis indicates that the error rate varies according to the difference between right and left surface deflection rates. Thus, for a difference in surface rates of twenty-five percent and a six degree step command, the maximum error would be approximately 1.25 degrees. This would cause a nuisance trip in the aileron or elevator servosystems. Such an asymmetric load would be likely only for antisymmetrically moving surfaces.

The loop gain and rate limit analysis results may be summarized as follows. For each percent difference in loop gain (representing a static error) or rate limit (representing an error due to asymmetric loading), an error of approximately 0.9 degrees will be contributed with each second the surfaces are commanded at the maximum rate. Whichever factor is larger should determine the error contribution.

The error contribution due to differences in the threshold non-linearity (shown in figure 16a) is insignificant for dif-

ferences of as much as 500 percent. Hysteresis differences of as much as 300 percent were also shown to have a negligible contribution to the error (shown in figure 16b).

The effect of noise in the system due to the EHSV is shown in figures 17a and 17b. This noise could be from the environment or it could be thought of as state noise resulting from the unmodeled characteristics of the servovalve. The effects were attentuated by the actuator. The curve resembles the curves for differences in rate limit because in the model the noise was added to the EHSV input. This resulted in a larger than 4 milliampere input current and thus, a larger control flow. Looking at just the amplitude of the error curve gives a more realistic view of the effect of noise sources in the EHSV. The effect on the error for a three percent addition of random white noise appears to be negligible.

The error contribution from noise introduced at the demodulator output is shown in figures 18a and 18b. This is a significant problem for the CSCM method because any nonidentical signals introduced at this point directly affects the error magnitude. This has already been illustrated by the problem associated with the demodulator ripple. An average difference in the demodulator outputs of 3.0 percent due to system noise results in an error that approaches 2.0 degrees. Filtering of the demodulator output will attenuate the high frequency noise but a compromise would have to be made in choosing the cut-off frequency. The actual position information could not be attenuated which would result in selection of a filter cut-off frequency that would not attenuate low frequencies. The extent of the noise problem would most effectively be determined by

actual measurements on the vehicle servosystems.

The combined effects are shown in figures 18a-18d. The demodulator noise overshadowed the error contributions from other sources. The error contributions in the physical system will not always be additive as was the case in these tests. This set of tests was a worst-case situation which used a range of differences that could be expected in the servosystems. The elevator and aileron servosystems with nominal computer threshold limits of 0.69 and 0.65 degrees, respectively, would be likely to cause a nuisance trip under the conditions of test case 1 or 2. The two canard servosystems could be very unlikely to cause a nuisance trip in any of the cases because of the wide buffer band created by a computer threshold limit of approximately 3.65 degrees.

The effect of the demodulator ripple voltage was analyzed previously for the symmetrically and antisymmetrically deflected surfaces. The two test cases are shown in figures 19a and 19b, respectively, for a sampled, rate-limited command of six degrees. The sampled command input does not appear to have a significant effect on the servosystem or the error value. The error magnitude for symmetrically moving surfaces, approximately 0.1 degrees, would be of some concern in the case of the elevators because of the small threshold limit and the resulting small buffer band. In the case of the antisymmetrically moving surfaces, the error magnitude of approximately 1.0 degrees would be critical for the ailerons since it exceeds the computer threshold limit. The nearly 25 percent decrease in the width of the canard buffer band would be undesirable

although it would be unlikely to cause a nuisance trip in itself. As mentioned earlier, filtering the demodulator output will reduce the ripple voltage error.

The modeling of the CSCM method might have been more precise had the higher-order dynamics and other possible non-linearities been included. The most probable servosystem variations in characteristics were not known which resulted in somewhat arbitrary choices for the ranges used in the computer analysis. The trends of the sensitivities to various differences, however, were clear. The probable effect of system noise was demonstrated but the choice of the magnitude was arbitrary. The amount of noise in the servosystems would best be determined by measurement of the physical system. The computer analysis results could then be used to approximate the error magnitude. The expected error contribution from each error source is summarized in table 6.

CONCLUDING REMARKS

The investiagtion of the cross-ship comparison monitoring (CSCM) method of failure detection revealed several problems associated with the technique. The selection of the appropriate computer threshold limit involves a trade-off between the possibility of a nuisance trip and the assurance that an actual failure will be detected in time.

There are several error sources which, if decreased or eliminated, would lessen the likelihood of a nuisance trip. These possible errors, due to differences between corresponding right and left servosystems for the canard, aileron, and elevator control surfaces, are as listed:

ERROR SOURCES	APPROXIMATE ERROR CONTRIBUTION	AMOUNTS OF DIFFERENCE BETWEEN SERVOSYSTEMS
Loop gain or rate limit	0.9 deg/second at maximum surface rate	1%
Threshold	7×10^{-5} deg	1%
Hysteresis	2.6×10^{-4} deg	1%
EHSV input noise	2×10^{-3} deg	1%
Ripple voltage for symmetrically deflected surfaces	0.02 deg/ deg of deflection	0%
Ripple voltage for anti-symmetrically deflected surfaces	0.14 deg/deg of deflection	0%

TABLE 6

SUMMARY OF ERROR SOURCES AND THE RELATIVE CONTRIBUTIONS FOR A 1% DIFFERENCE BETWEEN SERVOSYSTEMS

- Ripple voltage on the demodulator output.
- Electrical noise on the demodulator output.
- Asymmetric loading of the antisymmetrically moving control surfaces.
- Nonidentical loop gains.

The ripple voltage and electrical noise on the demodulator output signal could be attenuated by filtering the demodulator output. The low-frequency noise would still be present, however.

The problem due to asymmetric loading of the antisymmetrically moving surfaces could be a severe problem and should be analyzed further.

Nonidentical loop gains may be adjusted by changing the gain of the feedback amplifiers. Sufficient differences in the hydraulic components may require replacing the EHSV and servoactuator in one servosystem.

The likelihood of a nuisance trip may also be decreased by increasing the computer threshold limit. Decreasing the transfer delay time by using a faster switching relay for the lock up solenoid would allow a larger computer threshold limit to be selected. The selection of the computer threshold limit depends on the anticipated error rate. The error rate could be greater than or less than the maximum surface rate. The error rate, to some extent, depends on the commanded surface rate at the time of the failure. Therefore, the threshold limit should be chosen with the recognition that the error rate is dependent on the flight condition at the time of failure.

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APPENDIX

CSCM COMPUTER MODEL

PROGRAM LISTING

```
C*********************************************************************
C*********************************************************************
C
C     CROSSHIP COMPARE REDUNDANCY MANAGEMENT MODEL OF A TYPE B SERVO-
C     SYSTEM LOOP: GAINS ARE TAKEN FROM UPDATED HR INFORMATION.
C     A BILINEAR TRANSFORM IS USED FOR THE IMPLEMENTATION OF THE INTE-
C     GRATOR WITH ADDITIONAL NONLINEARITIES CALLED AS SUBROUTINES. THE
C     OUTPUTS TAKEN FROM THE DEMODULATORS ARE DIFFERENCED AND THE ERROR
C     IS GIVEN IN TERMS OF THE DIFFERENCE IN SURFACE POSITION (DEGREES).
C                                                        J. WOLF 10/77
C
C*********************************************************************
C*********************************************************************
C
C
C                              THIS IS THE INITIALIZATION PORTION. THE GAIN
C                              VALUES WILL BE READ, INITIAL CONDITIONS SET
C                              AND HEADINGS PRINTED.
C
C
      PROGRAM JXCC(INPUT,OUTPUT,TAPE1=INPUT,TAPE3=OUTPUT,TAPE4,TAPE6)
C
      REAL LVOT
      REAL LVDOUT(2),LVOTIN(2),ACT1(2)
C
      DIMENSION AMP(2),EHSV(2),ACT(2),LVOT(2),DEMOD(2),FEED(2)
      DIMENSION AMPIN(2),AMPOUT(2),EHSVIN(2),EHSOUT(2),ACTIN(2),ACTOUT(2
     *),ACTINP(2),FEEDIN(2),FDOUT(2),DEMODI(2),DEMODO(2),YYOUT(2)
C
      COMMON TIME,NPTS,THSPEC(2),RLSPEC(2),HYSPEC(2),NCASES
C
      WRITE(3,20)
   20 FORMAT(1H1,////20X,*CROSSHIP COMPARE REDUNDANCY MANAGEMENT OF THE
     *TYPE "B" SERVOSYSTEM*,/40X,*J. WOLF  10/77*///)
C
C
C                              IF THE NO. OF POINTS IS GREATER THAN 400
C                              THE COMMAND IS A 6.0 DEGREE STEP INPUT.  IF
C                              THE NO. OF POINTS IS EQUAL TO 400 THE INPUT
C                              IS A SINE WAVE OF AMPLITUDE EQUALING 5.0
C                              DEGREES AND FREQUENCY OF 5.0 HERTZ.  IF THE
C                              NO. OF POINTS IS LESS THAN 400 THE COMMAND
C                              IS A WHITE NOISE SIGNAL OF ZERO MEAN AND
C                              STANDARD DEVIATION OF 1.0 DEGREE.
C
C
C
C                              FIRST DATA CARD GIVES THE NO. OF CASES (I5)
C
      READ(1,9)NCASES
    9 FORMAT(I5)
C
      WRITE(3,99)NCASES
   99 FORMAT(//10X,*THE NO. OF CASES  IS*,I5//)
C
      DO 112 K=1,NCASES
C
```


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```
C                                   HEADING:
C
      WRITE(3,28)K
   28 FORMAT(//20X,*CASE NO. *,I2,//)
C
C                                   THE SAMPLE RATE OF THE SERVOSYSTEM IS READ
C                                   AND ALSO THE NO. OF DATA POINTS.
C
      READ(1,11)SSRATE,NPTS
   11 FORMAT(F9.3,2X,I5)
C
      WRITE(3,24)SSRATE,NPTS
   24 FORMAT(/10X,*THE SAMPLE RATE IS*,F9.3,* HZ*//10X,*THE NO. OF SAMPL
     *ES EQUALS*,I4//)
C
C                                   SERVOSYSTEM GAINS ARE READ FROM THE THIRD
C                                   DATA CARD IN A CASE. F10.4 FORMAT
C
      DO 100 I=1,2
C
      WRITE(3,21)I
   21 FORMAT(/20X,*SERVOSYSTEM *,I1,* ---- GAINS*,/)
C
      WRITE(3,22)
   22 FORMAT(10X,*AMPLIFIER*,12X,*EHSV*,15X,*ACTUATOR*,11X,*LVDT*,15X,
     **DEMODULATOR*,7X,*FEEDBACK*)
C
      WRITE(3,222)
  222 FORMAT(10X," MA/VDC  ",12X,"IN3/SEC-MA",9X,"  IN-2  ",11X,"VAC/IN"
     *,13X,"   VDC/VAC ",7X," MA/VDC"//)
C
      READ(1,10)AMP(I),EHSV(I),ACT(I),LVDT(I),DEMOD(I),FEFD(I)
   10 FORMAT(6(F10.4))
C
      WRITE(3,23)AMP(I),EHSV(I),ACT(I),LVDT(I),DEMOD(I),FEFD(I)
   23 FORMAT(10X,6(F8.4,11X)//)
C
C                                   DEADBAND, RATE LIMIT, AND HYSTERESIS VALUES
C                                   ARE INPUT AS PERCENTAGES OF ACTUATOR FULL
C                                   STROKE SPECIFICATIONS.  WITH THE DEADBAND
C                                   SPECIFICATION IT IS WITH RESPECT TO MAXIMUM
C                                   SERVOVALVE INPUT SPECIFICATIONS(+/- 4MA).
C
      READ(1,710)THSPEC(I),RLSPEC(I),HYSPEC(I)
  710 FORMAT(3(F10.7))
      THSPEC(I) = HYSPEC(I) / 4.*6.969*20.
C
      WRITE(3,713)
  713 FORMAT(10X,*HYSTERESIS AND DEADBAND ARE GIVEN AS PERCENT OF FULL
     *STROKE.  RATE LIMIT IS GIVEN AS PERCENT OF 90 DEG/SEC.*///)
C
C
      WRITE(3,711)I,THSPEC(I),RLSPEC(I),HYSPEC(I)
  711 FORMAT(10X,*LOOP*,1X,I1,//10X,*THRESHOLD VALUE =*,34X,F10.7,/10X,*
     *RATE LIMIT =*,9X,F10.7,/10X,*HYSTERESIS VALUE =*,3X,F10.7,//)
  100 CONTINUE
C
```

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```
C                                 LABELS ARE CHOSEN TO DESCRIBE THE VARIABLE.
C                                 INITIALIZATION OF VARIABLES AND INITIAL
C                                 CONDITIONS ARE SET-UP.
C
      PERIOD = 1.0/SSRATE
      ERROR = 0.0
      ICNT = 0
      YYIN =0.0
      TIME = 0.0
C
      DO 101 I=1,2
      AMPIN(I) =0.0
      AMPOUT(I)=0.0
      EHSVIN(I)=0.0
      EHSOUT(I)=0.0
      ACTIN(I) =0.0
      ACTOUT(I)=0.0
      LVDTIN(I)=0.0
      LVDOUT(I)=0.0
      FEEDIN(I)=0.0
      FDOUT(I) =0.0
      DEMODI(I)=0.0
      DEMODO(I)=0.0
      YYOUT(I) =0.0
C
C                                 ACTINP IS THE PREVIOUS ACTUATOR INPUT AND
C                                 ACT1 IS THE PREVIOUS ACTUATOR OUTPUT. THIS
C                                 SET OF VARIABLES IS FOR THE BILINEAR TRANS-
C                                 FORM OF THE INTEGRATOR.
C
      ACTINP(I)=0.0
      ACT1(I) = 0.
  101 CONTINUE
C
C                                 THERE ARE TWO SERVOSYSTEM LOOPS IN THIS
C                                 MODEL.  LOOP 1 REPRESENTS A RIGHT AILERON
C                                 OR CANARD, LOOP 2 REPRESENTS THE LEFT.  ALL
C                                 CHANGES IN THE SERVOSYSTEM CHARACTERISTICS
C                                 ARE PERFORMED ON THE RIGHT SURFACE WITH THE
C                                 LEFT ACTING AS A REFERENCE OR CONTROL.
C
C
C                                 ALTHOUGH THE SIGNAL IN THE PHYSICAL SYSTEM
C                                 IS INVERTED AT THE LVDT DEMODULATOR THE
C                                 MODEL DOES NOT INVERT THE SIGNAL UNTIL THE
C                                 SUMMING JUNCTION TO PROVIDE A CLEAR PLOT
C                                 PRESENTATION.
C
      WRITE(3,25)
   25 FORMAT(/12X,*TIME*,10X,*COMMAND INPUT*,10X,*ERROR OUTPUT*,15X,*LOO
     *P 1*,12X,*LOOP 2*,/10X,*(SEC)*,13X,* (DEG) *,14X,*   (DEG)  *,13X,
     **   (DEG)  *,8X,*   (DEG)  *//)
C
C                                 USING THE SUBROUTINE INPUT A COMMAND INPUT
C                                 IS GENERATED.
C
      CALL INPUT(YYIN)
```

```
      C
  111 WRITE(3,26)TIME,YYIN,ERROR,YYOUT(1),YYOUT(2)
   26 FORMAT(10X,F10.6,4X,F10.4,13X,E13.6,8X,E13.6,6X,E13.6)
      C
      C                          OUTPUT FILE FOR PLOT ROUTINE
      C
          WRITE(4)TIME,YYIN,ERROR,YYOUT(1),YYOUT(2)
      C
          ICNT = ICNT + 1
          IF(ICNT.EQ.NPTS)GO TO 112
      C
          TIME = TIME + PERIOD
      C
          CALL INPUT(YYIN)
      C
      C                          THIS IS LOOP 1 OR THE RIGHT CONTROL SURFACE
      C
          I = 1
      C
      C                          ALL BLOCKS ARE TREATED AS PURE GAINS
      C                          EXCEPT FOR THE ACTUATOR BLOCK.
      C
      C
      C                          SINCE THE INPUT IS GIVEN AS DEGREES THE
      C                          VALUE IS DIVIDED BY TWO SINCE FOR A +20 DE-
      C                          GREE COMMAND A +10 VOLTS SIGNAL MUST BE
      C                          APPLIED.
      C
                 AMPIN(I)  =  YYIN/2.
          AMPOUT(I)  =  AMP(I) * AMPIN(I)
          EHSVIN(I) = AMPOUT(I) - FDOUT(I)
      C
      C                          THRESH IS THE SUBROUTINE FOR MODELING A
      C                          DEADBAND OR THRESHOLD NONLINEARITY. IN THE
      C                          CLOSED LOOP RESPONSE DEADBAND GIVES THE
      C                          HYSTERESIS NONLINEARITY.
      C
          CALL THRESH(I,EHSVIN)
      C
      C                          THESE TWO LINES LIMIT THE EHSV INPUT CURRENT
      C
          IF(EHSVIN(I).LE.-4.0)EHSVIN(I) = -4.0
          IF(EHSVIN(I).GE.4.0)EHSVIN(I) = 4.0
      C
          EHSOUT(I)  =  EHSV(I) * EHSVIN(I)
                 ACTIN(I)  =  EHSOUT(I)
      C
      C                          ACTUATOR IS MODELED AS AN INTEGRATOR
      C
          ACTOUT(I)  =  ACT1(I)   + ACTIN(I) * ACT(I) * PERIOD / 2.0
         *                       + ACTIN(I) * ACT(I) * PERIOD / 2.0
      C
      C                          THE RATE LIMIT SUBROUTINE LIMITS THE RAM
      C                          MOVEMENT TO 2.312 IN./SEC. AS SPECIFIED.
      C
          CALL RLIMIT(I,ACTOUT,ACT1,PERIOD)
      C
```

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```
C                                THESE TWO LINES ARE THE POSITION LIMITS FOR
C                                THE ACTUATOR.
C
      IF(ACTOUT(I).GE..503)ACTOUT(I) = .503
      IF(ACTOUT(I).LE.-.503)ACTOUT(I) = -.503
C
              LVDTIN(I)  =  ACTOUT(I)
      LVDOUT(I)  =  LVDT(I) * LVDTIN(I)
              DEMODI(I)  =  LVDOUT(I)
      DEMODO(I)  =  DEMOD(I) * DEMODI(I)
C
C                                THE SURFACE POSITION ACCORDING TO THE DEMOD-
C                                ULATOR OUTPUT IS GIVEN IN DEGREES FOR PLOT
C                                CLARITY BUT ALSO TO SIMULATE WHAT THE ON-
C                                BOARD COMPUTER MIGHT BE SEEING WITH RESPECT
C                                TO NOISE.
C
              YYOUT(I)  =  (DEMODO(I) * 39.72)/(DEMOD(I) * LVDT(I))
C
              FEEDIN(I)  =  DEMODO(I)
      FDOUT(I)  =  FEED(I) * FEEDIN(I)
C
              ACTINP(I)  =  ACTIN(I)
      ACT1(I) = ACTOUT(I)
C
C
C                                THIS IS LOOP 2 OR THE LEFT CONTROL SURFACE
C
      I = 2
              AMPIN(I)  =  YYIN/2.
      AMPOUT(I)  =  AMP(I) * AMPIN(I)
C
      EHSVIN(I)  =  AMPOUT(I) - FDOUT(I)
      CALL THRESH(I,EHSVIN)
C
      IF(EHSVIN(I).LE.-4.0)EHSVIN(I) = -4.0
      IF(EHSVIN(I).GE.4.0)EHSVIN(I) = 4.0
C
      EHSOUT(I)  =  EHSV(I) * EHSVIN(I)
              ACTIN(I)  =  EHSOUT(I)
C
C                                ACTUATOR IS MODELED AS AN INTEGRATOR
C
      ACTOUT(I)  =  ACTOUT(I) + ACTIN(I) * ACT(I) * PERIOD / 2.0
     *                         + ACTINP(I) * ACT(I) * PERIOD / 2.0
C
      CALL RLIMIT(I,ACTOUT,ACT1,PERIOD)
C
      IF(ACTOUT(I).GE..503)ACTOUT(I) = .503
      IF(ACTOUT(I).LE.-.503)ACTOUT(I) = -.503
C
              LVDTIN(I)  =  ACTOUT(I)
      LVDOUT(I)  =  LVDT(I) * LVDTIN(I)
              DEMODI(I)  =  LVDOUT(I)
      DEMODO(I)  =  DEMOD(I) * DEMODI(I)
C
              YYOUT(I)  =  (DEMODO(I) * 39.72)/(DEMOD(I) * LVDT(I))
```

```
C
                FEEDIN(I)  =  DEMODO(I)
      FOOUT(I)  =  FEED(I) * FEEDIN(I)
C
                ACTINP(I)  =  ACTIN(I)
      ACT1(I) = ACTOUT(I)
C
C                                THE DIFFERENCE IN THE TWO MONITOR OUTPUTS
C                                IS CALCULATED AND PRINTED A  "ERROR."
C
      ERROR = YYOUT(1) - YYOUT(2)
C
      GO TO 111
C
C                                CALL TO PLOT ROUTINE
C
  112 CONTINUE
      REWIND 4
      DO 723 KM = 1,NCASES
      CALL SCRIBL(KM)
  723 CONTINUE
      REWIND 4
      CALL PLOT(0.,0.,999)
      REWIND 6
      STOP
      END
```

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```
      SUBROUTINE THRESH(J,VALUE)
      DIMENSION VALUE(2)
      COMMON TIME,NPTS,THSPEC(2),RLSPEC(2),HYSPEC(2),NCASES
C
C                                STORE THE SIGN
C
      IF(VALUE(J).LT.0.0)Z = -1.0
      IF(VALUE(J).GE.0.0)Z = +1.0
      DEAD = ABS(VALUE(J))
C
C                                EIGHT MA IS THE FULL STROKE SWING OF THE
C                                EHSV INPUT.
C
      SPECS = 4. * THSPEC(J)
C
C                                THE DEADBAND IS ADDED OR SUBTRACTED FROM
C                                THE EHSV INPUT.
C
      IF(DEAD.GE.SPECS)VALUE(J) = VALUE(J) -(Z * SPECS)
      IF(DEAD.LT.SPECS)VALUE(J) = 0.0
C
      RETURN
      END
```

```
      SUBROUTINE RLIMIT(I,OUT,OUT1,PER)
      DIMENSION OUT(2),OUT1(2)
      COMMON TIME,NFTS,THSPEC(2),RLSPEC(2)
C
C                                BY COMPARING THE SPECIFIED RATE LIMIT OF
C                                2.312 IN./SEC. TO THE DELTA POSITION IN ONE
C                                PERIOD A LARGER VALUE IS DECREASED TO THE
C                                SPECIFIED
C
      SPECS = 2.312 * RLSPEC(I)
      GG = (OUT(I) - OUT1(I))/PER
      ZZ = 1.
      IF(GG.LT.0.0)ZZ = -1.0
C
      IF((ABS(GG)).GT.SPECS)OUT(I) = SPECS*ZZ*PER+OUT1(I)
      RETURN
      END
```

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```
      SUBROUTINE INPUT(VALUE)
C
C                                THIS IS THE SUBROUTINE FOR THE COMMAND INPUT
C
      COMMON TIME,NPTS
C
C
      IF(NPTS.GT.400)VALUE = 6.
C
C                                RANDOM NOISE ,ZERO MEAN AND STANDARD DEVIA-
C                                TION OF 1.0.
C
      IF(NPTS.LT.400)VALUE = GRAND(0)
C
      IF(NPTS.EQ.400)GO TO 2
C
      GO TO 3
C
C                                SINE WAVE OF 5.0 DEGREES , 5.0 HZ.
C
    2 THETA = TIME * 6.28318  * .25
      VALUE = SIN(THETA)  * .06
C
    3 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE ANOISE(BP,N,K,MX)
      REAL MX
      DIMENSION BP(2),VALUE(2)
      COMMON TIME,NPTS,THSPEC(2),RLSPEC(2),HYSPEC(2),NCASES
C
C                          GRAND IS A WHITE NOISE GENERATOR OF ZERO
C                          MEAN A UNITY STANDARD DEVIATION
C
      VALUE(N)=GRAND(0)
C
C                          THE NOISE LEVEL IS GIVEN AS A PERCENT OF
C                          MAXIMUM SIGNAL LEVEL AT THE POINT OF INTER-
C                          EST. THIS MUST BE PROVIDED BY THE USER.
C
      BP(N) = VALUE(N) * .001 * MX  + BP(N)
      RETURN
      END
```

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```
      FUNCTION GRAND(N)
C                                                                       GRAND
C.... WRITTEN 9/22/75  A MYERS , NASA/FRC                               GRAND
C.... ADAPTED BY J BROWNLOW FROM                                        GRAND
C                                                                       GRAND
C           COMM OF THE ACM  ALGORITHM 488                              GRAND
C           DECEMBER 1974                                               GRAND
C           VOL 17 NO. 12                                               GRAND
C           PAGE 704                                                    GRAND
C                                                                       GRAND
C     ROUTINE RETURNS PSEUDO RANDOM NUMBER WITH                         GRAND
C     A GAUSSIAN DISTRIBUTION WITH ZERO MEAN A                          GRAND
C     STANDARD DEVIATION OF UNITY                                       GRAND
C                                                                       GRAND
C     NOTE: USES RANF TO SUPPLY UNIFORM PSEUDO                          GRAND
C           RANDOM NUMBER WITH UNIFORM DISTRIBUTION                     GRAND
C           OVER THE RANGE 0 TO 1.0                                     GRAND
C                                                                       GRAND
C     NOTE: REQUIRES ONE INITIALIZATION CALL                            GRAND
C                                                                       GRAND
C     NOTE: N IS A DUMMY ARGUMENT                                       GRAND
C                                                                       GRAND
      DIMENSION D(48)                                                   GRAND
      COMMON /GRANDS/ U                                                 GRAND
      DATA D/ .674489750, .475859630, .383771164, .328611323,           GRAND
     . .291142827, .263684322, .242508452, .225567444,                  GRAND
     . .211634166, .199924267, .189910758, .181225181,                  GRAND
     . .173601400, .166841909, .160796729, .155349717,                  GRAND
     . .150409384, .145902577, .141770033, .137963174,                  GRAND
     . .134441762, .131172150, .128125965, .125279090,                  GRAND
     . .122610883, .120103560, .117741707, .115511892,                  GRAND
     . .113402349, .111402720, .109503852, .107697617,                  GRAND
     . .105976772, .104334841, .102766012, .101265052,                  GRAND
     . .099827234, .098448282, .097124309, .095851778,                  GRAND
     . .094627461, .093448407, .092311909, .091215482,                  GRAND
     . .090155838, .089133867, .088144619, .087187293/                  GRAND
      A=0.0                                                             GRAND
      I=0                                                               GRAND
    1 CONTINUE                                                          GRAND
      U=U+U                                                             GRAND
      IF(U.LT.1.0)GO TO 2                                               GRAND
      U=U-1.0                                                           GRAND
      I=I+1                                                             GRAND
      A=A-D(I)                                                          GRAND
      GO TO 1                                                           GRAND
    2 CONTINUE                                                          GRAND
      W=D(I+1)*U                                                        GRAND
      V=W*(0.5*W-A)                                                     GRAND
    3 CONTINUE                                                          GRAND
      U=RANF(0)                                                         GRAND
      IF(V.LE.U)GO TO 4                                                 GRAND
      V=RANF(0)                                                         GRAND
      IF(U.GT.V)GO TO 3                                                 GRAND
      U=(V-U)/(1.0-U)                                                   GRAND
      GO TO 2                                                           GRAND
    4 CONTINUE                                                          GRAND
      U=(U-V)/(1.0-V)                                                   GRAND
```

```
      U=U+U                                                    GRAND
      IF(U.LT.1.0)GO TO 5                                      GRAND
      U=U-1.0                                                  GRAND
      GRAND=1-A                                                GRAND
      RETURN                                                   GRAND
    5 CONTINUE                                                 GRAND
      GRAND=A-W                                                GRAND
      END
```

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```
      SUBROUTINE SCRIBL(K)
      COMMON TIME,NPTS,THSPEC(2),PLSPEC(2),HYSPEC(2),NCASES
      REAL BUF(2048),T(1000),DDATA(1000),Y(1000),LP1(1000),LP2(1000)
      DIMENSION NITLE(4),STORE(50),S(600),SS(600),SSS(600),TT(600)
C
      CALL PLOTS(BUF,2048,6)
      CALL FACTOR(2.0/2.54)
      CALL PLOT(2.,2.,-3)
      DATA NITLE/10HTIME HISTO,10HRY,SFC    ,10H   CASE NO,10H
     */
C
C                                THIS SUBROUTINE PLOTS THE COMMAND INPUT,
C                                THE LEFT AND RIGHT SURFACE MOVEMENTS AND
C                                THE ERROR BETWEEN THE TWO VERSUS TIME.
C
      ENCODE(10,1,NITLE(4))K
    1 FORMAT(2X,I2,6X)
C
C                                SET VARIABLES FOR ILLUSTRATING THE SAMPLED
C                                DATA EFFECT
C
      IJ = 1
      II = 1
      S(IJ) = 0.
      SS(IJ)  = 0.
      SSS(IJ) = 0.
      TT(IJ) = 0.
      DO 777 J = 1,NPTS
      READ(4)T(J),Y(J),DDATA(J),LP1(J),LP2(J)
C
C                                A SAMPLE AROUND THE APPROPRIATE SAMPLE TIME
C                                IS TAKEN AND HELD TILL THE NEXT SAMPLE TIME
C
      IF(T(J).LT.((1./53.3)*II))GO TO 777
      II= II+1
      IJ = IJ + 2
      S(IJ) = DDATA(J)
      S(IJ-1) = S(IJ-2)
      SS(IJ) = LP1(J)
      SS(IJ-1) = SS(IJ-2)
      SSS(IJ) =  LP2(J)
      SSS(IJ-1) = SSS(IJ-2)
      TT(IJ) = T(J)
      TT(IJ-1) = T(J-1)
  777 CONTINUE
C
C                                THE DATA IS SCALED. SINCE A SCALE FACTOR OF
C                                EIGHT IS UNDESIRABLE IF IT SHOULD APPEAR
C                                THE EIGHT SUBROUTINE CHANGES THE SCALE
C                                FACTOR TO TEN.
C
      CALL SCALE(DDATA,2.0,NPTS,1)
      CALL EIGHT(DDATA,NPTS)
      CALL SCALE(T,7.0,NPTS,1)
      CALL EIGHT(T,NPTS)
      CALL SCALE(Y,2.0,NPTS,1)
      CALL EIGHT(Y,NPTS)
```

```
      CALL SCALE(LP1,2.0,NPTS,1)
      CALL SCALE(LP2,2.0,NPTS,1)
      CALL EIGHT(LP2,NPTS)
C
C                                THE SCALE FACTORS AND STARTING VALUES FOR
C                                THE SAMPLED POINTS ARE TRANSFERRED TO THE
C                                RESPECTIVE ARRAYS.
C
      TT(IJ+1) = T(NPTS+1)
      TT(IJ+2) = T(NPTS+2)
      S(IJ+1) = CDATA(NPTS+1)
      S(IJ+2) = CDATA(NPTS+2)
      SS(IJ+1) = LP1(NPTS+1)
      SS(IJ+2) = LP1(NPTS+2)
      SSS(IJ+1) = LP2(NPTS+1)
      SSS(IJ+2) = LP2(NPTS+2)
C
C                                TIME AXIS
C
      CALL AXIS (0.,0.,NITLE,-40,7.0,0.,T(NPTS+1),T(NPTS+2))
      CALL PLOT(0.,7.5,-3)
C
C                                ERROR AXIS
C
      CALL AX90 (0.,0.,"ERROR,DEG   ",+12,2.0,90.,DDATA(NPTS+1),DDATA(NP
     *TS+2))
C
C                                ERROR PLOT
C
      CALL LINE(T,DDATA,NPTS,1,0,0)
C     CALL LINE(TT,S,IJ,1,0,0)          SAMPLE RATE EFFECT
      CALL PLOT (0.,-2.5,-3)
C
C                                COMMAND AXIS
C
      CALL AX90 (0.,0.,"COMMAND,DEG  ",+13,2.0,90.,Y(NPTS+1),Y(NPTS+2))
C
C                                COMMAND PLOT
C
      CALL LINE (T,Y,NPTS,1,0,0)
      CALL PLOT(0.,-2.5,-3)
C
C                                RIGHT SURFACE AXIS
C
      CALL AX90(0.,0.,"RT,DEG",+6,2.0,90.,LP1(NPTS+1),LP1(NPTS+2))
C
C                                RIGHT SURFACE PLOT
C
      CALL LINE(T,LP1,NPTS,1,0,0)
C     CALL LINE(TT,SS,IJ,1,0,0)          SAMPLE RATE EFFECT
      CALL PLOT(0.,-2.5,-3)
C
C                                LEFT SURFACE AXIS
C
      CALL AX90(0.,0.,"LT,DEG",+6,2.0,90.,LP2(NPTS+1),LP2(NPTS+2))
C
```


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```
C                                   LEFT SURFACE PLOT
C
      CALL LINE(T,LP2,NPTS,1,0,0)
C     CALL LINE(TT,SSS,IJ,1,0,0)        SAMPLE RATE EFFECT
      CALL SCALE(DDATA,2.0,NPTS,1)
C
C                                   CODE TO ARRANGE SCALE FACTORS FOR A CUMULA-
C                                   TIVE PLOT OF THE ERROR DATA OF ALL CASES
C
      STORE(K) = DDATA(NPTS+1)
      CALL SCALE(DDATA,2.0,NPTS,-1)
      STORE(K*2) = DDATA(NPTS+1)
      IF(K.NE.NCASES)GO TO 5
      CALL SCALE(STORE,9.5,NCASES*2,1)
      CALL EIGHT(STORE,(NCASES*2))
      DDATA(NPTS+1) = STORE(NCASES*2+1)
      DDATA(NPTS+2) = STORE(NCASES*2+2)
      CALL PLOT(12.,0.,-3)
      CALL AX90(0.,0.,"SECONDS",-7,7.0,0.,T(NPTS+1),T(NPTS+2))
      CALL AX90(0.,0.,"ERROR OUTPUT ALL CASES,DEG",+26,09.5,90.,DDATA(NP
     *TS+1),DDATA(NPTS+2))
      REWIND 4
C
C                                   ALL CASES PLOT
C
      DO 7 L = 1,NCASES
      DO 6 N = 1,NPTS
      READ(4)T(N),Y(N),DDATA(N),LP1(N),LP2(N)
    6 CONTINUE
      CALL LINE(T,DDATA,NPTS,1,0,0)
    7 CONTINUE
    5 CALL PLOT(12.,-2.,-3)
      RETURN
      END
```

```
      SUBROUTINE EIGHT(DAT,NPTS)
      DIMENSION DAT(1000)
C
C                          THE SCALE FACTOR OF DAT ARRAY DIMENSIONED
C                          NPTS POINTS IS CHECKED TO SEE IF IT IS A
C                          FACTOR OF EIGHT(MIGHT BE 8,80, OR 800 ETC.)
C                          THEN CHANGE IT TO 10, 100,  .1 , ETC.
C
      Z= 1.
      IF(DAT(NPTS+2).LT.0.)Z=-1.
      D = ALOG10(ABS(DAT(NPTS+2)))
      E = ALOG10(8.)
      CC = D-INT(D)
C
      IF(ABS(CC-E).GT..001.AND.ABS(CC-(E-1.)).GT..001)RETURN
C
      IF(CC.LT.0.)D= INT(D)+0.
C
      IF(CC.GT.0.)D= INT(D)+1.
      DAT(NPTS+2) =(10.**D)*Z
      RETURN
      END
```


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CONVERSION FACTORS TO SI UNITS

To correct from-	To-	Multiply by
psi	N/m^2	6894.76
in	m	0.0254
in^{-2}	m^{-2}	1550.15
Vac/in	Vac/m	39.37
deg/in	deg/m	39.37
in^3/sec-mA	m^3/sec-mA	1.639×10^{-5}
in/sec	m/sec	0.0254

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1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA CR-144879		

4. Title and Subtitle	5. Report Date
INVESTIGATION OF THE CROSS-SHIP COMPARISON MONITORING METHOD OF FAILURE DETECTION IN THE HiMAT RPRV	December 1978
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No
James A. Wolf	
9 Performing Organization Name and Address	10. Work Unit No.
University of Kansas Center for Research 2291 Irving Dr. Lawrence, Kansas 66044	11. Contract or Grant No. NSG-4012
12. Sponsoring Agency Name and Address	13. Type of Report and Period Covered
National Aeronautics and Space Administration Washington, D.C. 20546	Contractor Report - Topical
	14. Sponsoring Agency Code H-1078

15. Supplementary Notes

NASA Technical Monitor: Dwain A. Deets, Dryden Flight Research Center

16. Abstract

The HiMAT RPRV uses cross-ship comparison monitoring of the actuator RAM positions to detect a failure in the aileron, canard, and elevator control surface servosystems. Some possible sources of nuisance trips for this failure detection technique are analyzed. A FORTRAN model of the simplex servosystems and the failure detection technique were utilized to provide a convenient means of changing parameters and introducing system noise. The sensitivity of the technique to differences between servosystems and operating conditions was determined. The cross-ship comparison monitoring method presently appears to be marginal in its capability to detect an actual failure and to withstand nuisance trips. Several suggestions are given to alleviate potential problems. The LVDT demodulator outputs should be filtered to attenuate the ripple signal and system noise. Each set of servosystems should be set as closely as possible to the same loop gain. A higher sample rate along with a faster switching relay would allow a larger failure threshold value to be used.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
Failure identification HiMAT Research aircraft Digital flight control Microprocessors	Unclassified - Unlimited STAR Category: 05

19. Security Classif (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
Unclassified	Unclassified	100	$4.75

*For sale by the National Technical Information Service, Springfield, Virginia 22161