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SPACE SHUTTLE RUDDER/SPEEDBRAKE SUBSYSTEM ANALYSIS

Job Order 35-489

(NASA-CR-147415) SPACE SHUTTLE RUDDER/SPEEDBRAKE SUBSYSTEM ANALYSIS (Lockheed Electronics Co.) 160 p HC $6.75 CSCL 22B

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For

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13. ABSTRACT

This report describes the CSMP program, its uses, some limitations and its application to the R/SB subsystem model. This report also analyzes the Space Shuttle R/SB subsystem using the CSMP to evaluate the Rockwell math model contained in Rockwell publication SD 74-SH-0324.

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R/SB SUBSYSTEM
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SPACE SHUTTLE RUDDER/SPEEDBRAKE SUBSYSTEM ANALYSIS

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LIST OF ABBREVIATIONS AND ACRONYMS

ASA	Aerosurface Servo Amplifier
CPU	Central Processor Unit
CSMP	Continuous System Modeling Program
DSBRHL	Degrees Speedbrake in Rudder Hinge Line
FCS	Flight Control System
GPM	Gallons Per Minute
HM	Panel Hinge Moment
HMR	Panel Hinge Moment of Rudder
HMSB	Panel Hinge Moment of Speedbrake
HP	Hewlett Packard
JCL	Job Control Language
KHST	Servo Value Torque Motor Hysteresis
LPDEG	Left Panel Degrees
MDM	Multiplexer/Demultiplexer
PDU	Power Drive Unit
RHL	Rudder Hinge Line Reference System
RIN	Rudder Input Command
RPDEG	Right Panel Degrees
R/SB	Rudder and/or Speedbrake
RPM	Revolutions Per Minute
SIN	Input Speedbrake Command

1. SUMMARY

This report presents the analysis of the Space Shuttle Rudder/ Speedbrake (R/SB) subsystem using the Continuous System Modeling Program (CSMP) to evaluate the Rockwell math model contained in Rockwell publication SD 74-SH-0324 (reference 1). The R/SB subsystem fits into the overall avionics system as depicted in figure 1-1.

The report describes the CSMP program, its uses, some limitations and its application to the R/SB subsystem model. The appendices contain definitions of the constants and variables used in the program. The report highlights three (3) areas of analysis: 1) step response, 2) ramp response, and 3) the delay time or deadspace observed in system response. Data obtained using the CSMP program was further processed in a continuous format in a manner similiar to that shown in figure 1-2.

The step response is used to evaluate three (3) factors: 1) the linearity of the output response, 2) the accuracy of the output response, and 3) the response of the system to a step command. Various step commands were separately addressed first to the Rudder, then to the Speedbrake. When one channel was driven the other was set to zero or null.

The Rudder displayed a 1 percent accurate output response for all three commands, thus demonstrating acceptable linearity and accuracy. The Speedbrake did not, however, meet reasonable standards since accuracy and linearity were in error in excess of 6 percent. The slew rate of both systems was fast enough to meet maximum software speed requirements of 12 deg/sec.

The ramp command was used to evaluate two factors: 1) the tracking ability of both the Rudder and Speedbrake, and 2) the ability of the hydraulic system to meet worst case specifications. It was found that after initial system dynamics had settled out, the system output followed the input with an undetectable graphical error in both Rudder and Speedbrake response. It was also found that the R/SB hydraulic motors were indeed capable of meeting the specification supplied from Rockwell and that their performance would not overtax the hydraulic system.

The deadspace or system delay time to input command was found to possibly be longer than expected but since there does not appear to be any specification on this parameter, it was difficult to judge.

Of the four contributors to the deadspace (the Servo valve flapper motor, the Summer and Mixer gear trains, and the Power Drive Unit (PDU) gear train), it was found that the PDU gear train contributed the most to the deadspace. The PDU gear train was responsible for over 57 percent of the delay.

It was established during the analysis that the deadspace was command-dependent, i.e., as the command rate increased, the deadspace decreased. A 10-deg/sec Rudder command exhibits a deadspace of 75 milliseconds (ms) whereas a 5-deg/sec Rudder command has a deadspace of 125 ms. This report contains methods for the determination of both Rudder and Speedbrake deadspace for various input ramp commands.

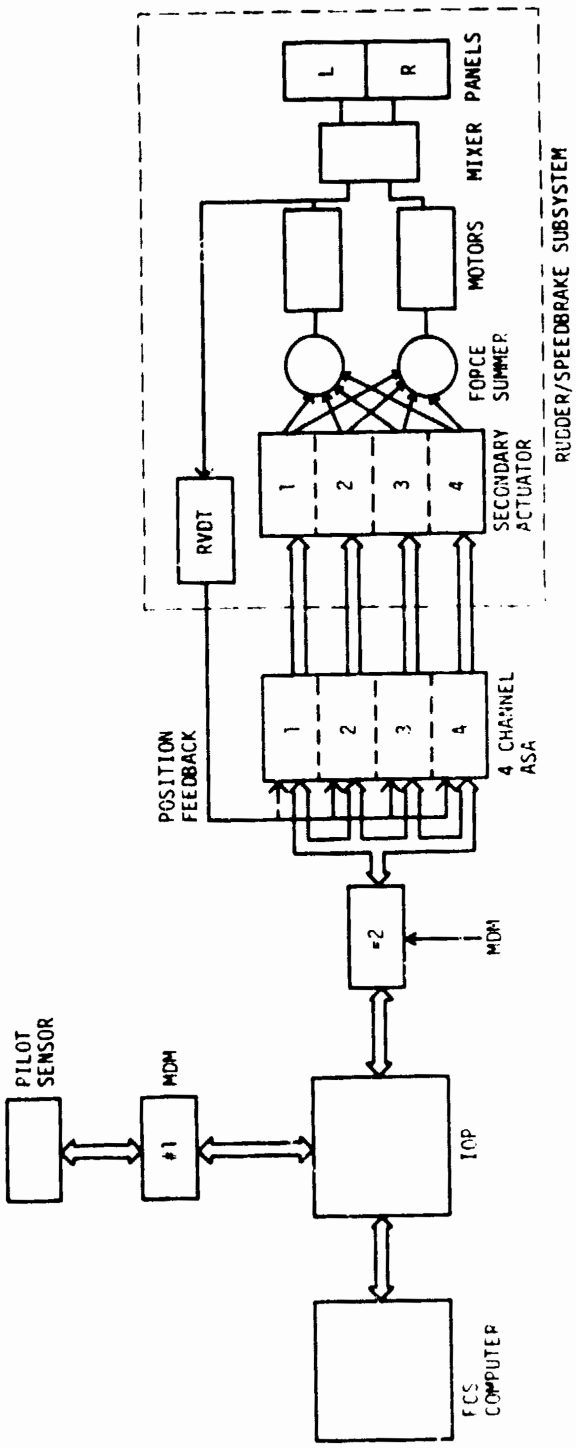


Figure 1-1. – Rudder/Speedbrake subsystem in avionics system.

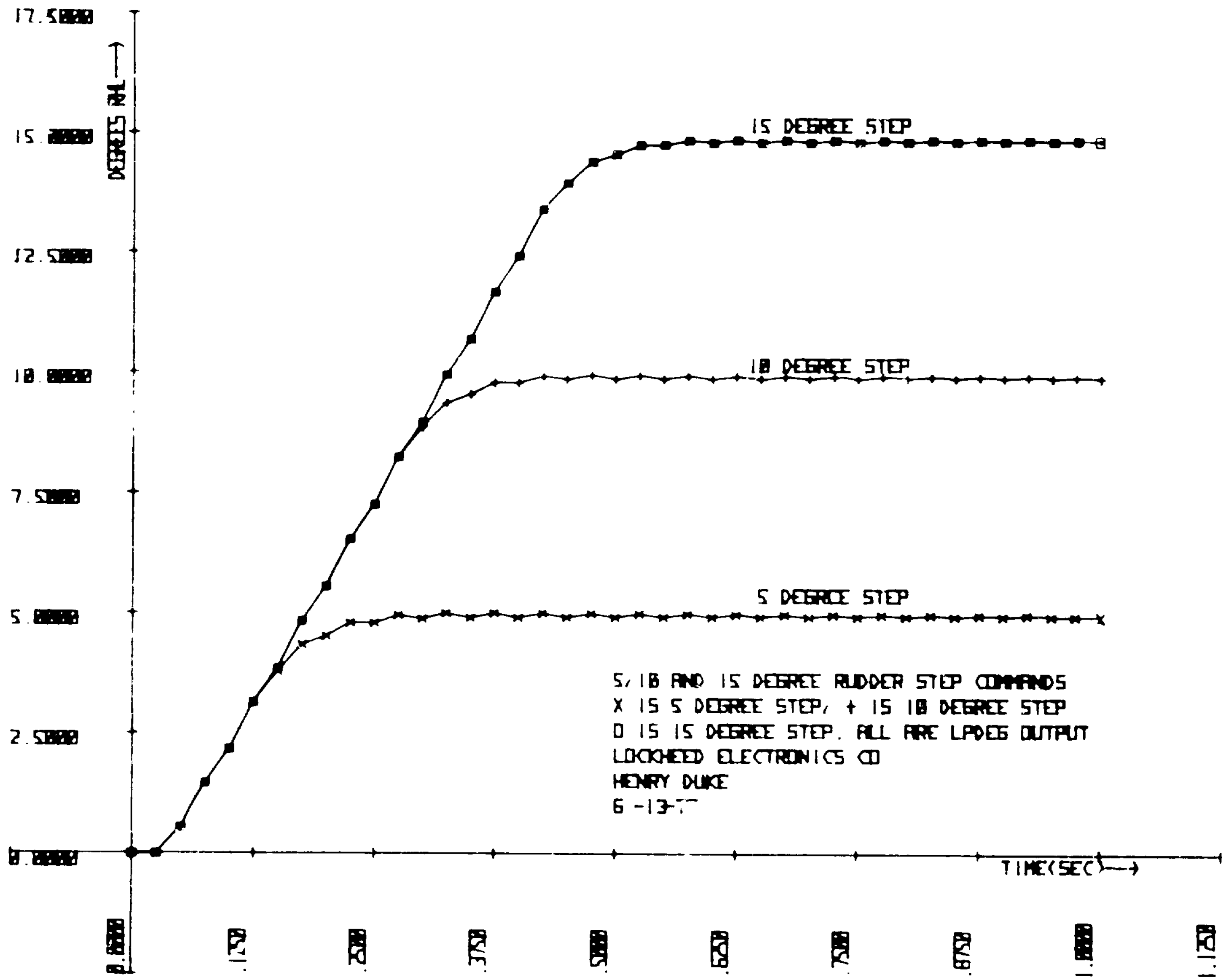


Figure 1-2. – Example of plot format.

2. INTRODUCTION

The R/SB subsystem is one of the major flight control systems developed for use as primary flight control in the Space Shuttle. This report presents a basic analysis of the R/SB using a 4-channel software model developed by LEC engineers from inputs by Rockwell. Rockwell developed a mathematical description of the R/SB (ref. 1) which was used in conjunction with CSMP III (ref. 2) to develop the software model used in this analysis. This report makes use of the CSMP model to investigate some basic system response characteristics such as linearity and response time.

3. CSMP PROGRAM

The CSMP program is an extremely versatile program with a variety of useful capabilities. It features a debug subroutine which, for a predetermined number of points, will list each of the variables and their value for each integration sampling time.

One of the major advantages of CSMP is its sort capability. The computer will sort the equations as necessary, place them in order and operate on them without the programmer being concerned with the order of occurrence of the equations.

Subroutines are also available to allow for the handling of 1st and 2nd order functions without the necessity of programming separate integration subroutines. Outputs can also be shown in logarithmic readout, standard readout, and other useful possibilities.

A listing of the CSMP program used is given in appendix A. The CSMP program is broken into five separate sections:

1. INPUT JCL - initial setup instructions to computer.
2. INITIAL - system constants and initial conditions.
3. DYNAMIC - system equations.
4. TERMINAL - integration method and time, start time, finish time, plot time, etc., necessary to produce outputs and load in outputs to be plotted or listed.
5. OUTPUT JCL - sort and perform necessary operations to produce output.

During the "reading in" of the data described in sections 2, 3 and 4 above, the basic CSMP program can be broken into with basic FORTRAN as a subroutine to perform decision-making.

There are some limitations, however, in the performance of the CSMP model. Some of the more serious limitations are:

1. Since the computer performs as a sampling data system, a limitation exists on the size of the sampling time for integration purposes. These limits depend upon the integration routine used and internal system oscillations encountered. Some recent experimentation with those limits resulted in the determination that the 50 μs integration time used in the program shown in appendix A was in fact approaching maximum. Using a larger integration time resulted in numerical instability. The method used in the present CSMP integration process is the Runge-Kutta fixed step which, in this program, works quite well with a 50 μs integration period.

2. The achievement of reasonable results in R/SB performance requires large amounts of CPU time. As an example, an average 1-second run requires almost 20 minutes CPU time.

3. There is a limitation on the total possible number of statements which may be used in the model. The present model utilizes over 580 statements which approaches the 600 statement limit. This borderline condition prohibits any possible large expansions to accomodate system changes. Elimination of portions of the program will be necessary to accomplish large changes which require additional cards.

Except for its few limitations, the CSMP program is a versatile tool in the analysis of control systems.

Appendix F contains a list of the variables and constants used in the CSMP program and their definitions or functional descriptions.

4. STEP RESPONSE

The plots obtained for 5-, 10- and 15-degree R/SB steps are given in appendix B. The first six (6) plots contained therein are the original CSMP computer printout plots whereas, the others were obtained by plotting the CSMP values using a HP 9820 calculator and a HP 9862A calculator plotter. For a further discussion of this technique, see appendix G.

Of major concern was the accuracy of both Rudder and Speedbrake deflections. Rudder input commands were based upon a 5-volt-input level causing a 27.1-degree Rudder Hinge Line (RHL) deflection of each panel in the same direction. Speedbrake input commands were based upon a 5-volt input command causing a panel separation angle of 49.3 degrees (RHL).

After panel movement settled down to an approximate steady-state value, a number of final points were averaged and this was used as the steady-state value of panel deflection (or separation). The resulting plots are shown in appendix B (B-7 through B-12). Table I gives the results of this analysis. An obvious discrepancy exists here since the +15 degree Speedbrake step has not reached its steady-state value. The 5- and 10-degree steps have, however, and the error achieved here will be used in this analysis. From this, it can be observed that the Rudder response exhibits a reasonable error, but the Speedbrake is excessive. Magnifying the 10-degree steps in both Rudder and Speedbrake steady-state graphs (B-9 and B-10) reveals that a 20 Hertz oscillation exists on the output waveshape. This is quite low level, however, with the peak-to-peak value being down by over 23 dB from the steady-state value of 9.9003 volts for the Rudder and 9.306 volts for the Speedbrake. The blowup reveals that the Speedbrake is still rising at a rate of 0.5 deg/sec. At this rate, it would take 20 seconds to arrive at

TABLE I.– STEP RESPONSE STEADY-STATE VALUES

Type*	Input Command Step (Deg)	Average	No. of Points	Error (%)
R	5	4.9495	50	1.01
R	10	9.9003	50	1.00
R	15	14.842	50	1.05
SB	5	4.555	50	8.9
SB	10	9.306	50	6.94
SB	15	No final ss** value achieved	50	Undetermined

*R is Rudder

SB is Speedbrake

**steady state

the 10-degree steady-state position. As shown in section 5, this increase will become steady-state in well under 20 seconds.

The delay time from input stimulus to output response is also of importance. The major contribution to the delay time comes from deadspace contained in the PDU gear train and in the Servo valve. Some other contributions exist in the summer and mixer gears, but, as shown in section 6, they are negligible. The delay times for the Rudder and Speedbrake step commands are given in table II with respective plots contained in appendix C.

Values shown in table II are based upon the first usable point given in the readout. The actual starting point will be occurring in the 5-ms period preceeding the first usable point as shown in figure 4-1. Linear interpolation could be used to obtain a more accurate figure but since the system response is not linear, the improvement in accuracy would, at best, be small. Therefore, work in this area is found in section 5 which contains a general discussion of delay for any command.

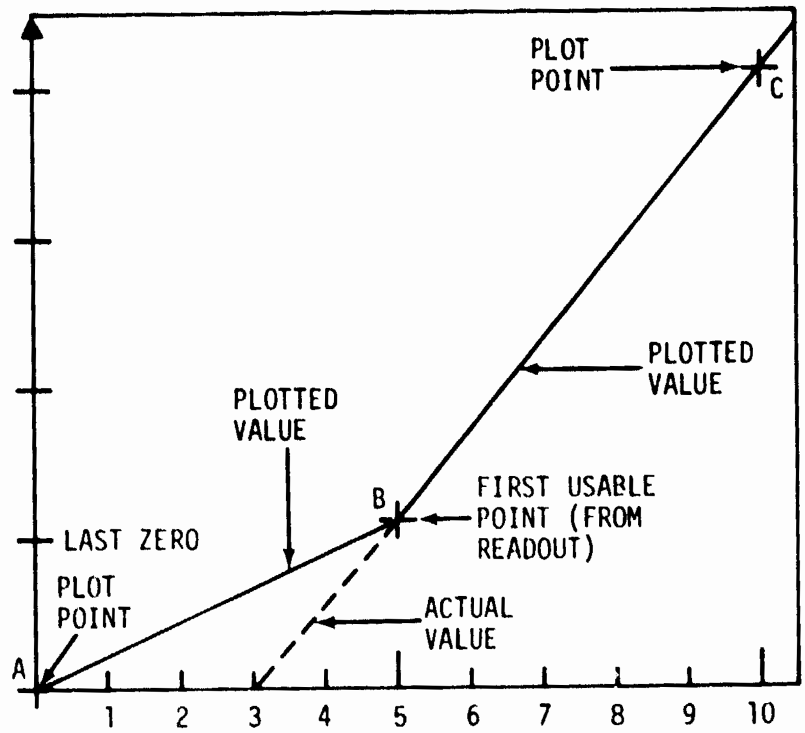
The slew rate of the response curves in figure 4-1 corresponds to the maximum possible system response to an input signal. This is the hardware limit of performance. The hardware limit must exceed the software limit to allow the system to respond to maximum possible system change commands.

A step command from the pilot will result in a ramp output from the ASA to the input of the Servo valves as shown in figure 4-2. (For a more detailed discussion of the input command, see appendix I).

At the present time, the Autopilot rate limits the MDM output to 12.1 deg/sec from the Rudder, 6.1 deg/sec (opening) and 10.85 deg/sec (closing) from the Speedbrake. The output panel

TABLE II.- DELAY TIME TO STEP COMMAND

Input	Delay Time		
	Start Command (Sec)	Start Response (Sec)	Delay (Sec)
RIN (Rudder)	0.005	0.025	0.020
SIN (Speedbrake)	0.005	0.040	0.035



4.1 – Graphical method of determining starting point of plot.

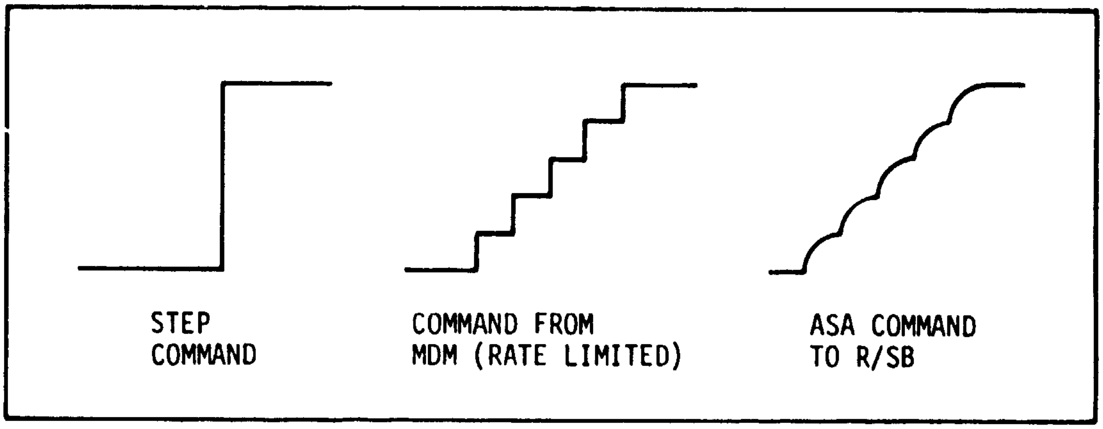


Figure 4.2 – Input command waveshapes.

speed for an input step must exceed these values for proper performance. The slew rates for Rudder and Speedbrake are given in table III. Since 5-, 10- and 15-degree step slew rates are the same for both Rudder and Speedbrake (see appendix B), only the values for a 10-degree step are listed.

The Rudder slew rate corresponds to the change in the left panel position (LPDEG) and the Speedbrake corresponds to the change in the angular separation of the Speedbrake (DSBRHL). Both values are RHL and fall well outside of the minimum opening panel deflection rates of 12.1 and 6.1 for the Rudder and Speedbrake.

TABLE III.— RUDDER AND SPEEDBRAKE MAXIMUM SLEW RATE

Command	Slew Rate (deg/sec)
Rudder 10-deg step	34.07
Speedbrake 10-deg step	21.20

5. RAMP RESPONSE

This section reviews the response of the R/SB systems to ramp input stimuli. Each of the four input channels in one of the systems (Rudder or Speedbrake) is addressed with a ramp while the four channels of the other system are addressed to the null (zero) position. All components are taken as operational and at a temperature of 100° F.

Figures 5-1, 5-2, 5-3 and 5-4 give the output (RIN1 vs LPDEG or SIN1 vs DSBRHL) for Rudder and Speedbrake input commands. Figures 5-2 and 5-4 demonstrate that the R/SB outputs follow the inputs so close that an error is undetectable. To obtain meaningful results, it was necessary to observe Rudder performance for over 2 seconds and Speedbrake performance for over 6 seconds. As can be seen, the delay on these final segments is constant, being 78 ms for the Rudder and 450 ms for the Speedbrake.

Initially, at the beginning of response, the situation is quite different as shown in figures 5-5 and 5-6. The initial delay in the action of the panels is caused wholly by the hysteresis dead-space. This is discussed and shown in more detail in section 6. After initial response of the panels to the stimulus, the system exhibits an additional slowness in coming up to speed. After running speed is reached, the system overshoots and then, after a period of time, returns to following the input command. This is characteristic of the ramp response of a working hardware model where the motor speed comes up to rated speed then overshoots and dampens out to follow the input.

In May, some information was received from Rockwell in a letter concerning their model. Graphs were sent of the R/SB performance which included the hydraulic motor speed for a single motor with three (3) operating, output panel position and output panel rates for both Rudder and Speedbrake. The information received corresponded to a 10.03-deg/sec Rudder command and Speedbrake commands

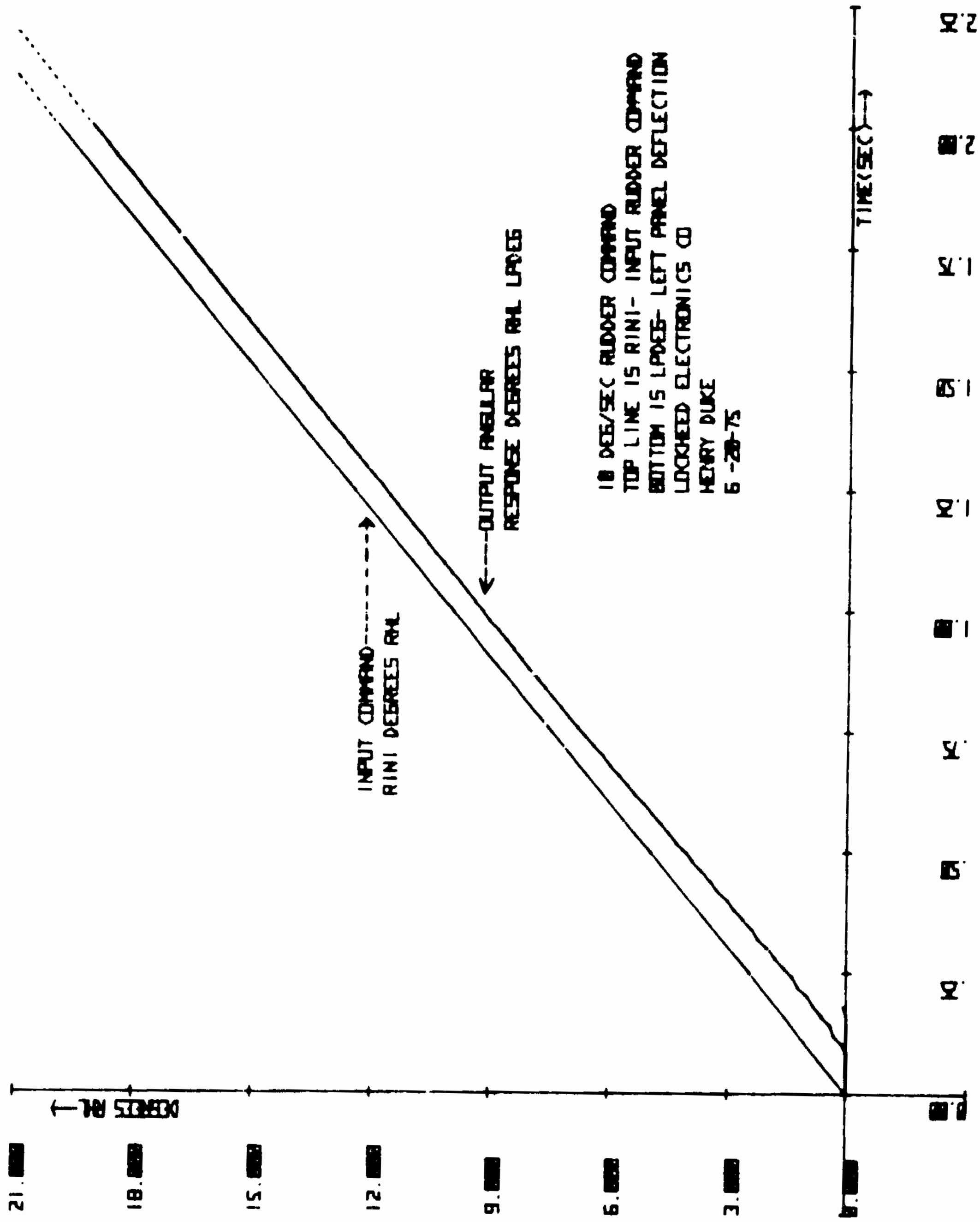


Figure 5-1. - Rudder input stimulus and output response.

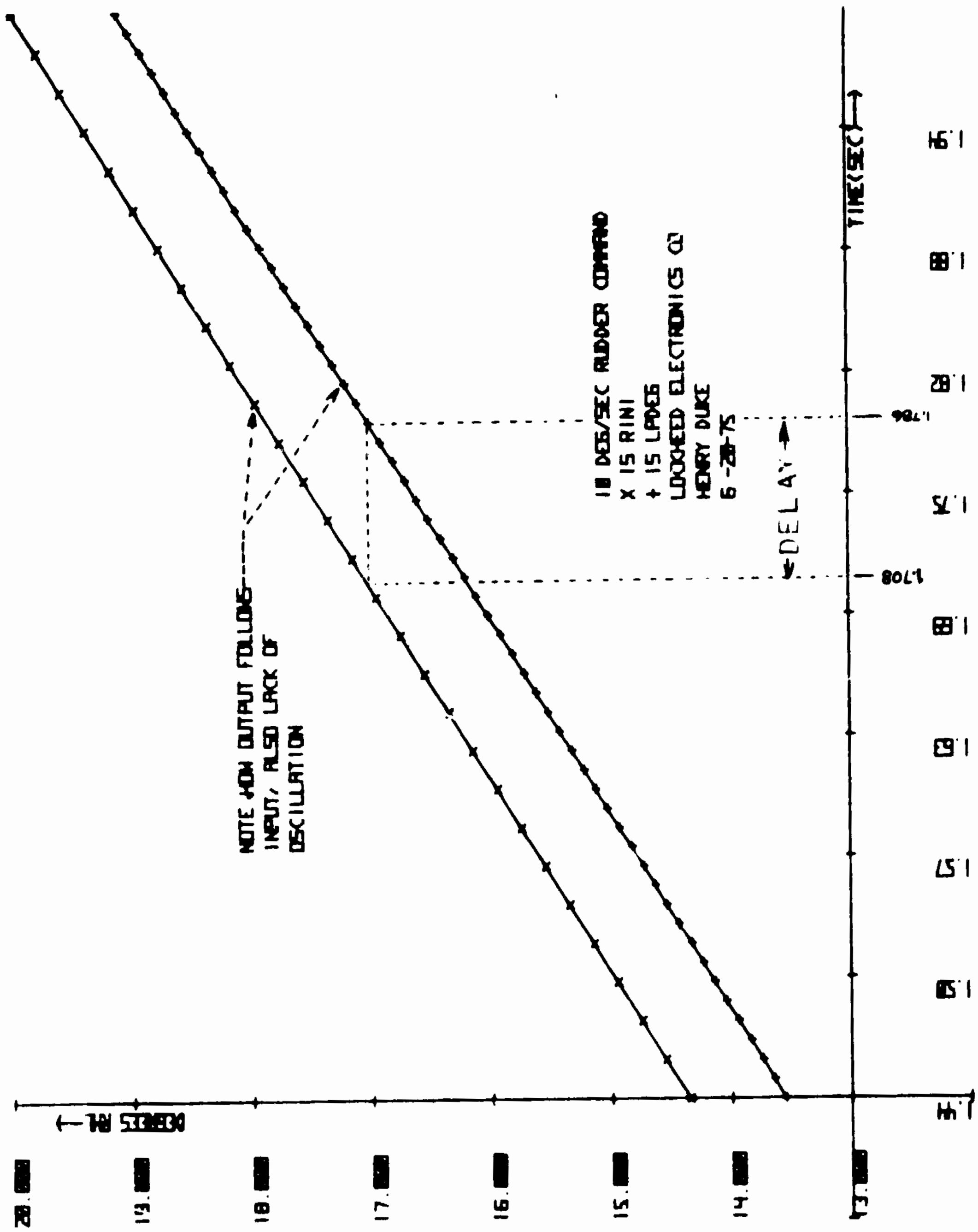


Figure 5-2. – Rudder input stimulus and output response magnified.

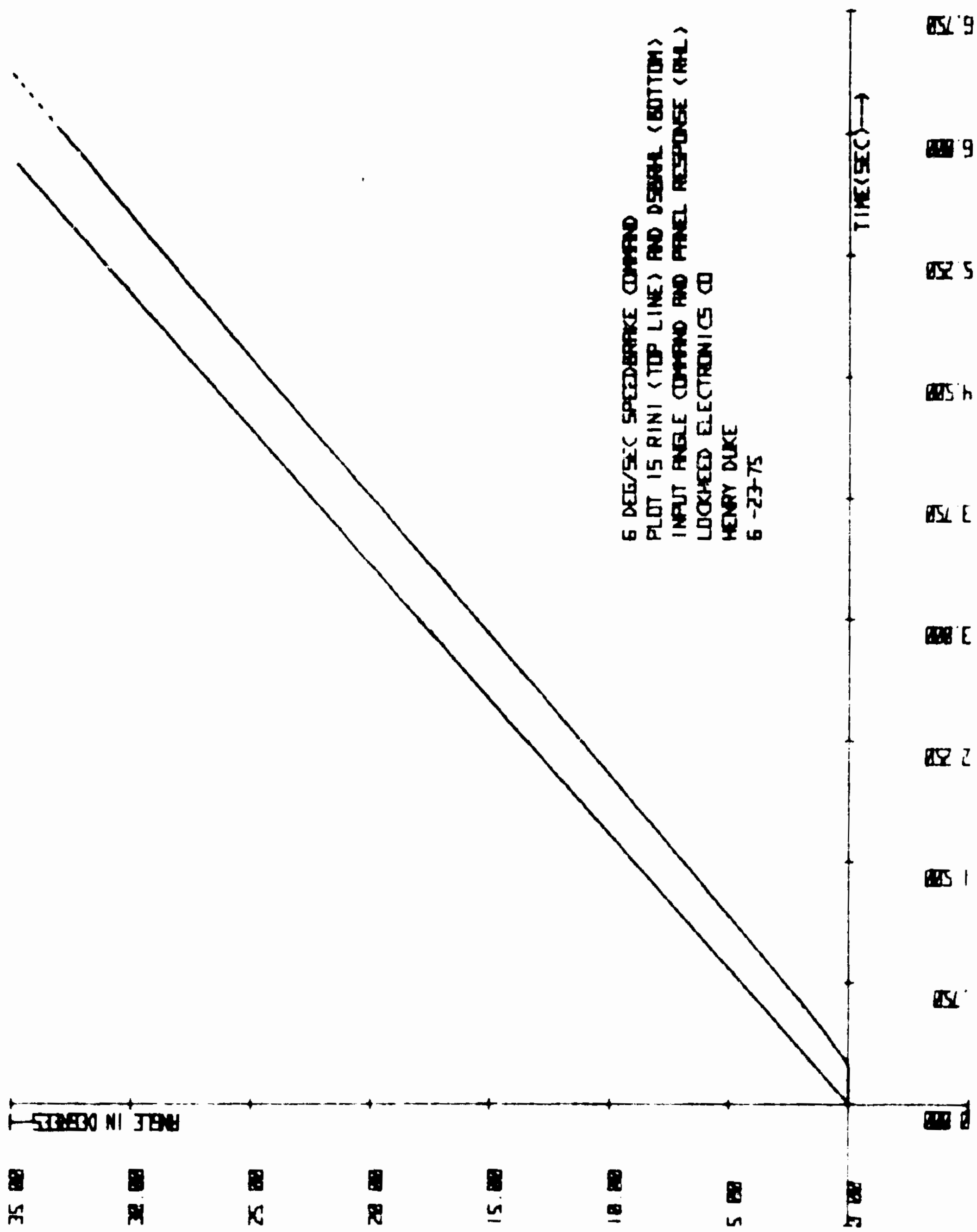


Figure 5-3. – Speedbrake input stimulus and output response.

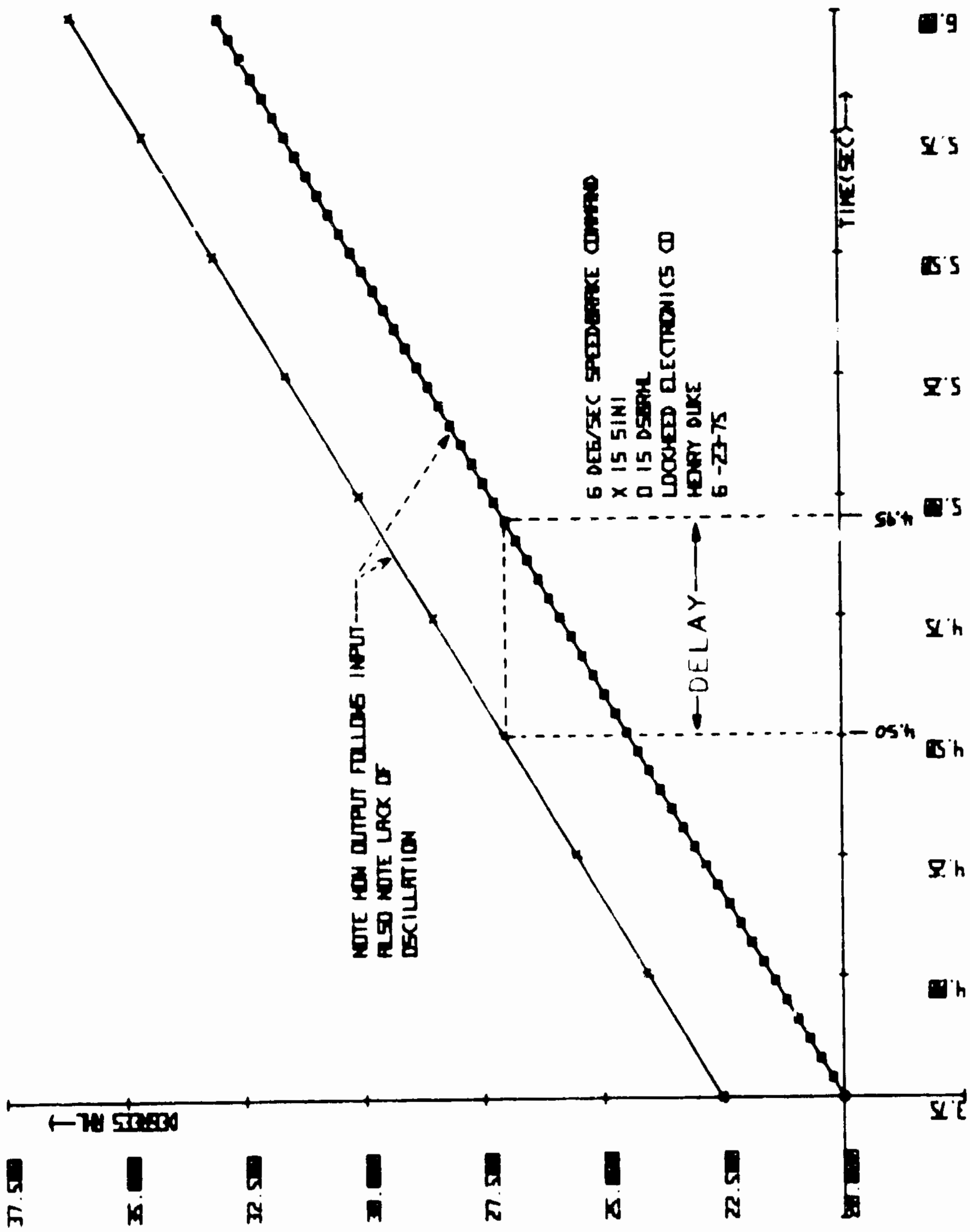


Figure 5-4. — Speedbrake input stimulus and output response magnified.

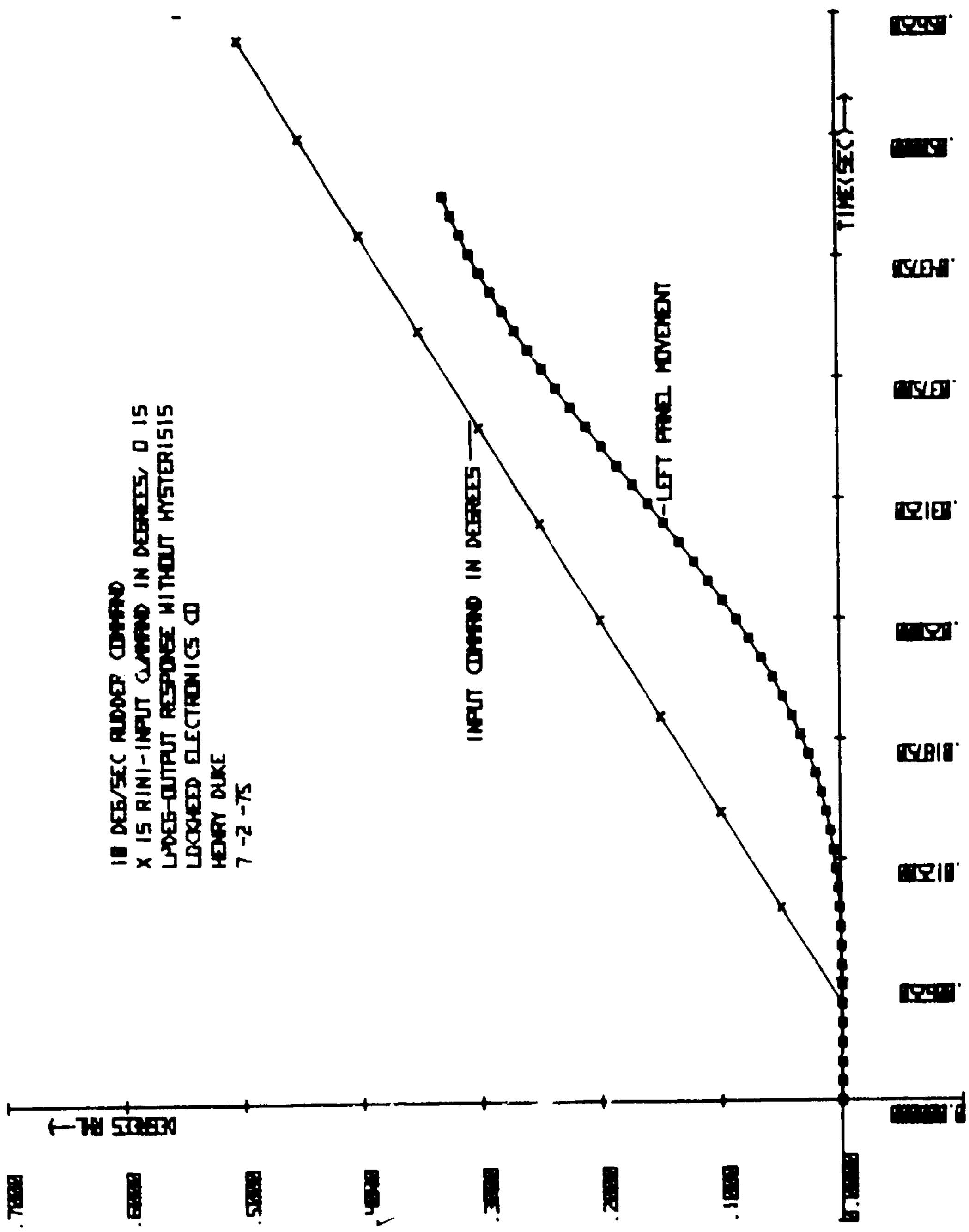


Figure 5-5. - Rudder initial response.

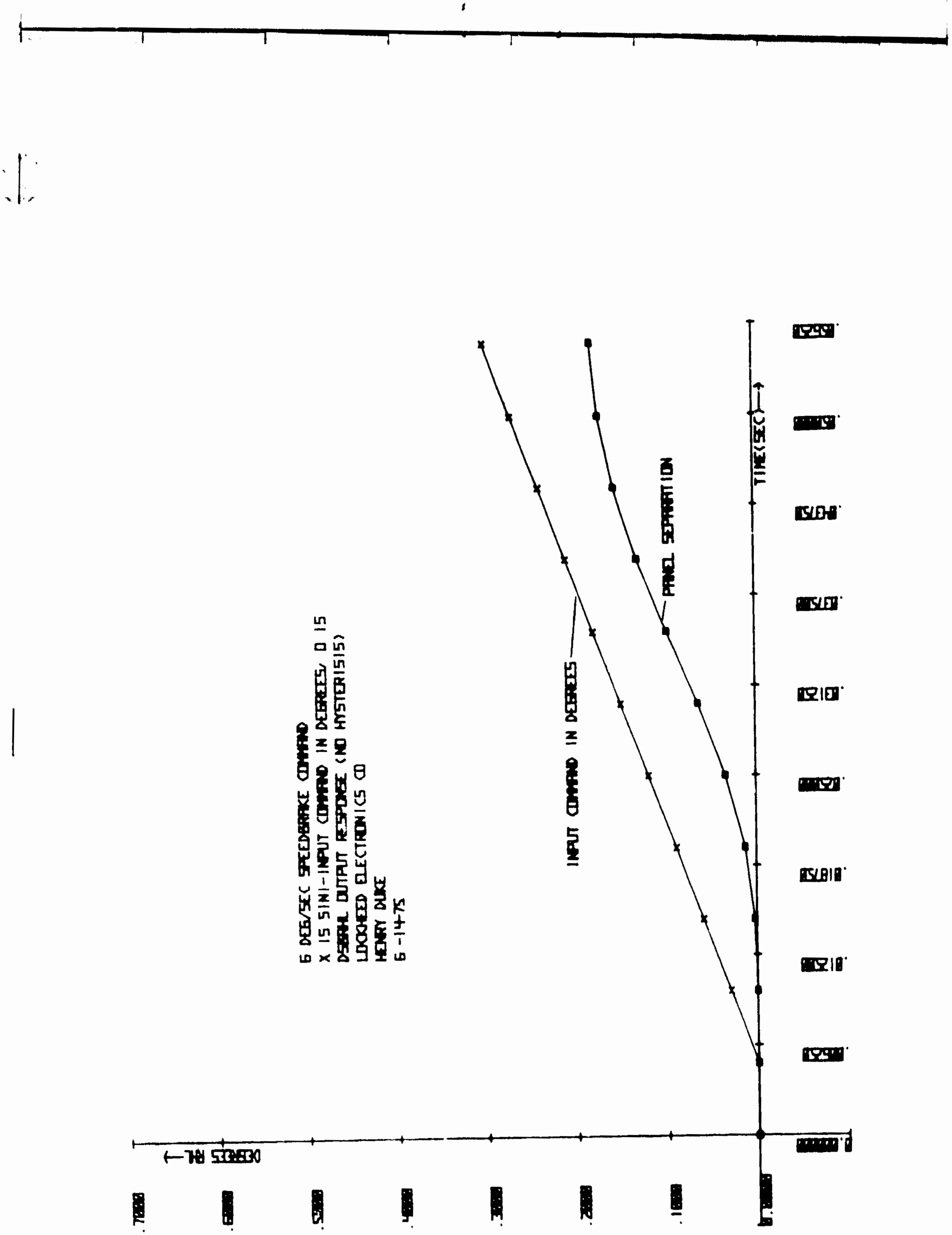


Figure 5-6. - Speedbrake initial response.

respectively. Graphs cont[illegible]ned within this letter are contained in appendix D for reference. Also contained in appendix D are corresponding CSMP plots. Prior to receipt of this data, a telephone conversation with personnel at Rockwell revealed that for 3-motor operation, the Rudder motor speed-per-motor should be 2850 rpm and the Speedbrake motor speed for a single motor should be 2550 rpm. The plots contained in appendix D show the results found in table IV.

The Rockwell model had given the motor speed for 10.03 deg/sec. This has been interpolated to 6 deg/sec which is the value given:

$$\frac{10 \text{ deg/sec}}{6 \text{ deg/sec}} = \frac{450}{X} \text{ rad/sec}$$

$$X = 270 \frac{\text{rad}}{\text{sec}} \times \frac{60 \text{ sec}}{1 \text{ min}} \times \frac{1 \text{ rev}}{2\ \pi\text{rad}}$$

$$= 2578 \text{ rpm}$$

Speed for the Lockheed values were taken as an average over a number of points, as shown in figures D-3 and D-8, using methods in appendix G. Note that the Rudder error in Lockheed's model is very small whereas the Speedbrake error is over 2 percent. It has also been determined that the stated motor speeds are well within the capabilities of the motors as their capability is dependent mainly upon the maximum possible flow. Appendix E features a writeup of the necessary fluid input to produce a given output rotational speed. Maximum output speed for 3-motor operation is that for the 12.1-deg/sec Speedbrake closing. Using interpolation:

$$\text{Speed} = \frac{(12.1)(2850)\text{rpm}}{10} \cong 3449 \text{ rpm}$$

For a speed of 3449 rpm, the motor input will have to be about 7.8 gallons per minute (GPM), well within the 22.3-GPM maximum (ref. 1 para. 3.1.2.4.4).

Since the 12.1-deg/sec input command is the software limit, it represents worst case and it is easily seen that both Rudder and Speedbrake hydraulic sources will be capable of producing the necessary input flow.

TABLE IV.— COMPARISON OF MOTOR SPEEDS

Type Of Input	Rate (deg/sec)	Motor Speed		
		Rockwell telephone (RPM)	Rockwell model (RPM)	Lockheed (RPM)
Rudder	10	2850	2836	2848.8
Speedbrake	6	2550	2578	2611.2

6. DEADSPACE

For this analysis, the deadspace[1], or "deadband" as it is sometimes called, is the time elapsed from the input stimulus to one or more hysteresis loops to the time when the output responds. Observed in this section are the effects of each individual loop upon deadspace and the total cumulative effects of all loops. Appendix H plots give the deadspace measured in all four hysteresis loops for both Rudder and Speedbrake performance for a 10-deg/sec Rudder and a 6-deg/sec Speedbrake command. This section, however, deals with their effects for various commands and how to calculate the deadspace for any input command (see figure 6-1).

There are fourteen (14) hysteresis loops located in the R/SB subsystem. Four of these are common to both Rudder and Speedbrake command responses, whereas the remaining ten are peculiar to either Rudder or Speedbrake command chains. Table V lists the location of each hysteresis loop, the value in arc-min, and approximate time contribution for a 10-deg/sec or 6-deg/sec Rudder or Speedbrake command. Note that a Rudder 10-deg/sec command will not be felt equally at the beginning of the first loop as a Speedbrake 10-deg/sec command. This is caused by a variation of input factors called KRV and KSBV. KRV is shown in figure 6.2 with KSBV in a similar position for the Speedbrake. For a further discussion of the differences, refer to appendix I.

A series of various input Rudder commands were input and the cumulative effects of hysteresis deadspace were plotted as shown in figure 6-1. Each plot point is the cumulative time from input stimulus to the first observed output response.

As observed, the largest contributor to deadspace is the PDU gear train. Although the value for the PDU gear train hysteresis is

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[1] Deadspace pertains to the special DEADSPACE function utilized in CSMP programming (see reference 2).

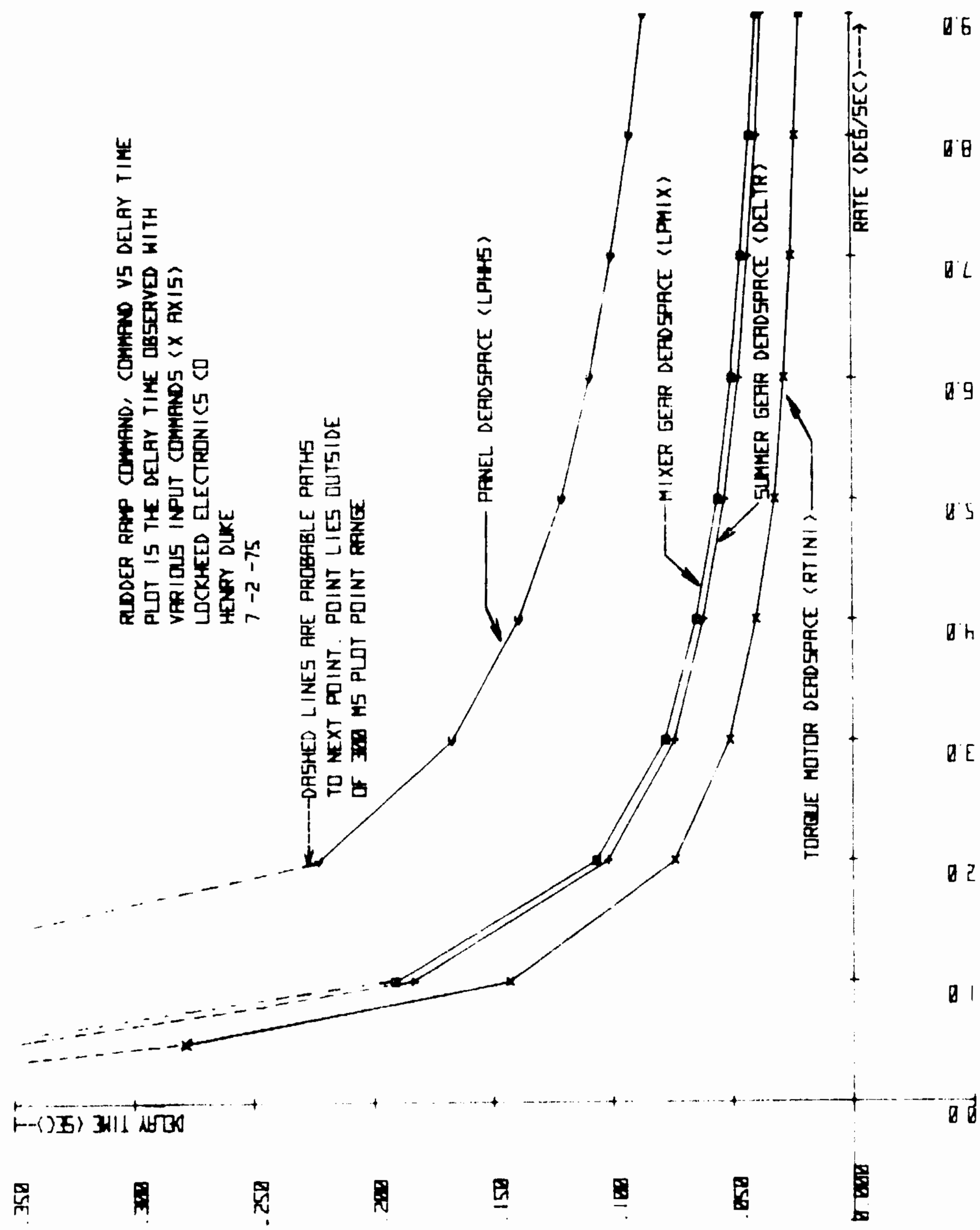
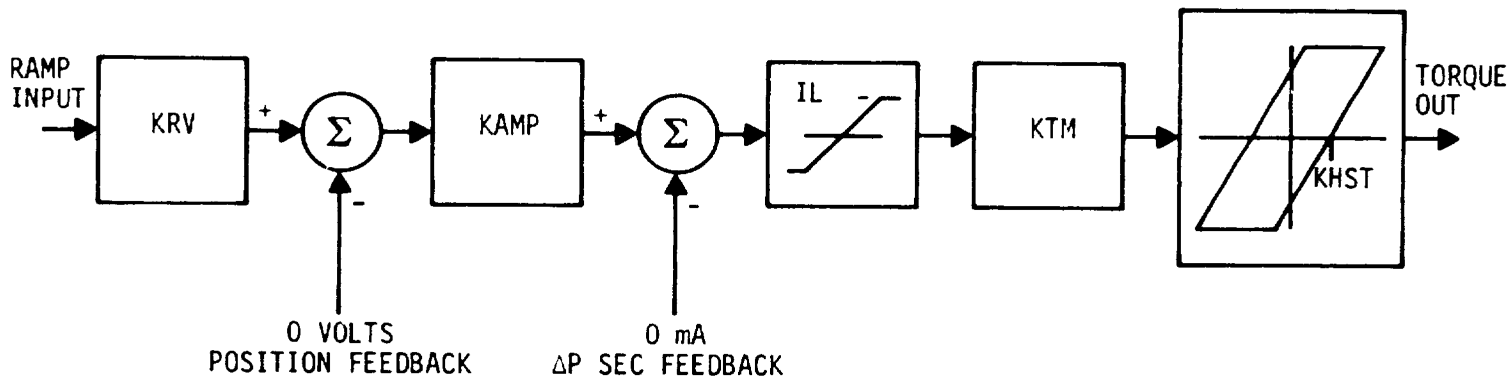


Figure 6-1. – Cumulative Rudder deadspace for various input commands.



KRV = Rudder conversion factor = $0.1845 \frac{\text{Volts}}{\text{Degree}}$

KAMP = ASA gain = $17.5 \frac{\text{mA}}{\text{Volt}}$

IL = Flapper valve torque motor current limit = ± 8 mA

KTM = Current to torque gain = $0.045 \frac{\text{In-lb}}{\text{mA}}$

KHST = Flapper torque hysteresis = 0.02 In-lb

Figure 6-2. — R/SB subsystem from input to flapper output.

TABLE V.— HYSTERESIS CONTRIBUTION TO DEADSPACE

Hysteresis Loop	Description	Value (arc-min)	Time For (sec)	Command (deg/sec)
1R	Flapper torque motor	0.4	0.014	10 R
2R	Flapper torque motor	0.4	0.014	10 R
3R	Flapper torque motor	0.4	0.014	10 R
4R	Flapper torque motor	0.4	0.014	10 R
5R	Summer gears	163.8	0.015	10 R
1SB	Flapper torque motor	0.4	0.036	6 S
2SB	Flapper torque motor	0.4	0.036	6 S
3SB	Flapper torque motor	0.4	0.036	6 S
4SB	Flapper torque motor	0.4	0.036	6 S
5SB	Summer gears	163.8	0.020	6 S
*1R/SB	Mixer gears left panel	71.8	0.003	10 R
*2R/SB	Mixer gears right panel	71.8	0.003	10 R
*3R/SB	PDV gears left panel	10.0	0.043	10 R
*4R/SB	PDV gears right panel	10.0	0.043	10 R

*Time shown is for 10-deg/sec Rudder command only.

apparently much less than some of the other values shown in table V, its deadspace is disproportionately greater. This is caused by the large gear ratio that exists from the motor outputs to the panel. This gear ratio is 5,099:1 for the Rudder and 15,472:1 for the Speedbrake.

From figure 6-1, it can be ascertained that the output delay is approximately 4 times the input delay. This means that the 0.074 sec delay for the 2 deg/sec run will take 0.29 seconds to be felt on the panels.

By knowing the delay involved in the first loop, the remaining hysteresis deadspace can be found easily by approximation. This factor of 4 applies to the Rudder only. The Speedbrake was not run for various inputs as was the Rudder, but from the 6 deg/sec command, it is easily found that the factor is 11.

1. Rudder deadspace output panel movement is:

$$\text{Deadspace} \cong \frac{(4)(0.145)}{\text{slope of input}} = \frac{0.58}{\text{slope}}$$

$$\text{i.e., } 10 \text{ deg/sec} \cong 0.058 \text{ sec deadspace}$$

2. Speedbrake deadspace output panel movement is:

$$\text{Deadspace} \cong \frac{(11)(0.08)}{\text{slope of input}} = \frac{0.88}{\text{slope}}$$

$$\text{i.e., } 6 \text{ deg/sec} \cong 0.146 \text{ sec deadspace.}$$

A block diagram of the first hysteresis loop is shown in figure 6-2. This shows one channel (of a 4-channel servo valve) from the input command to the flapper torque output.

Figures 6-3 and 6-4 show the times for various input commands to reach threshold. These are further listed in tables VI and VII.

A single 10-deg/sec run was made without the hysteresis loops present to determine if there were other unknown factors contributing to the deadspace. This is given in figure 6-5. Although figure

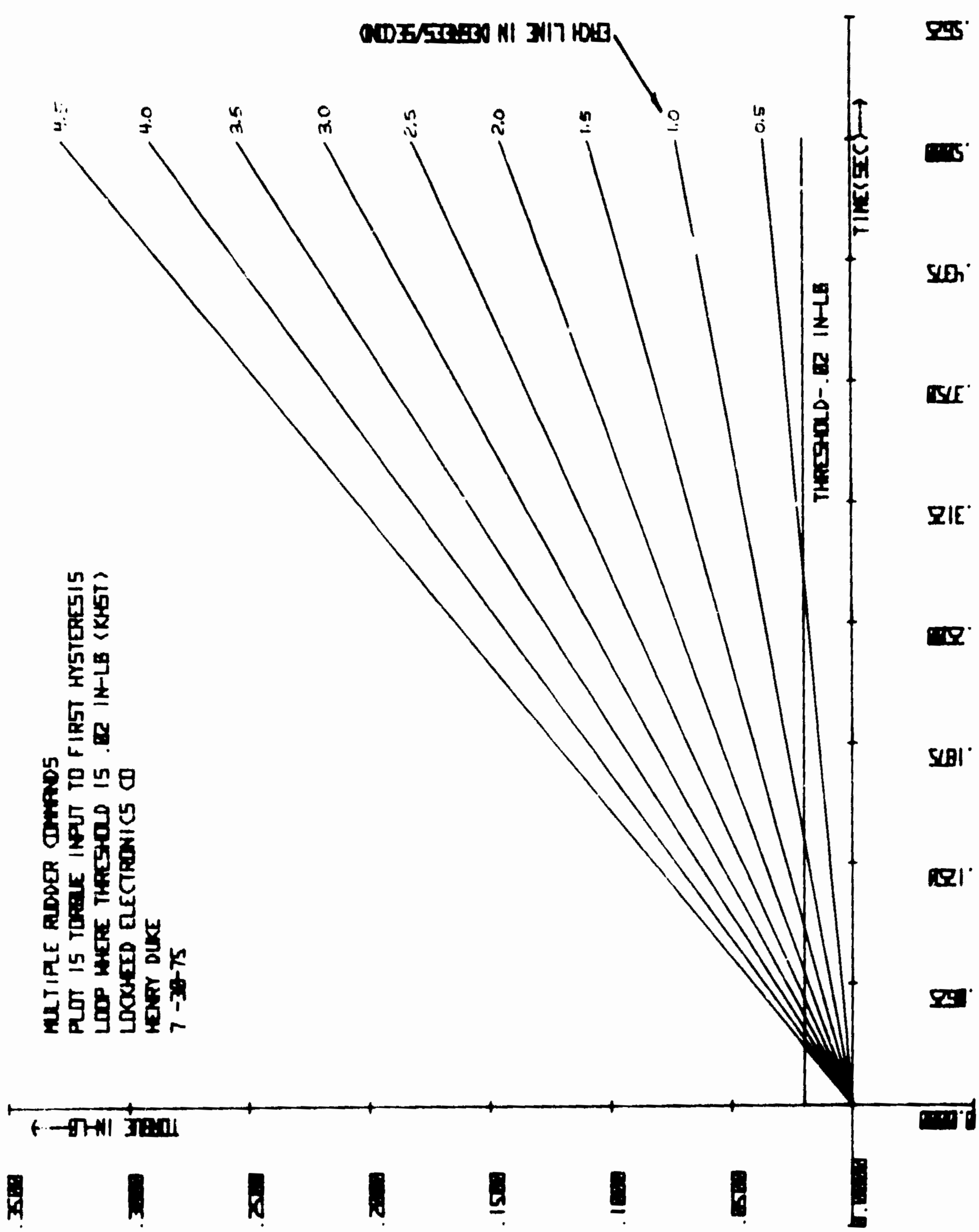


Figure 6-3. — Various input ramps seen at first hysteresis loop for Rudder.

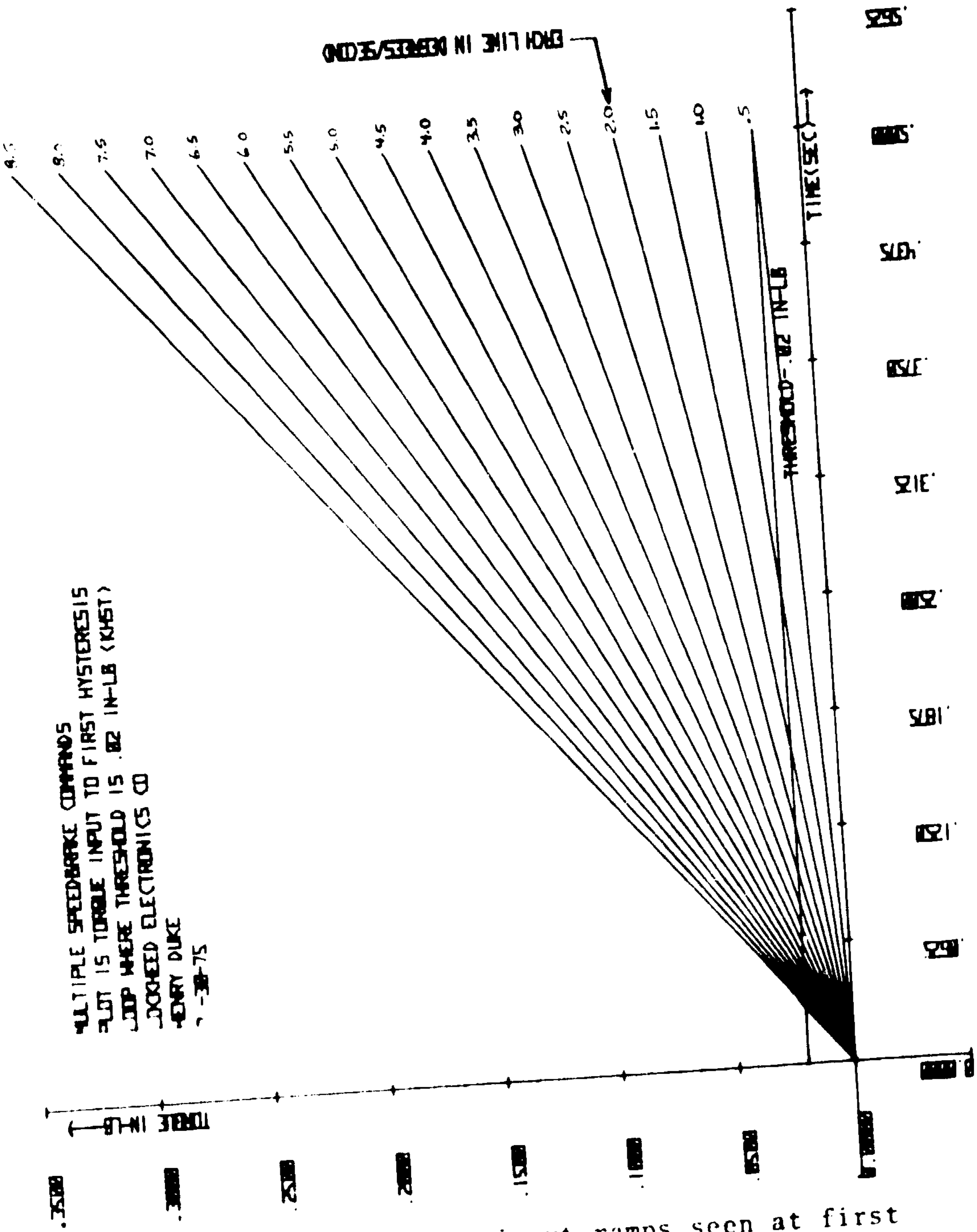


Figure 6-4. - Various input ramps seen at first hysteresis loop for Speedbrake.

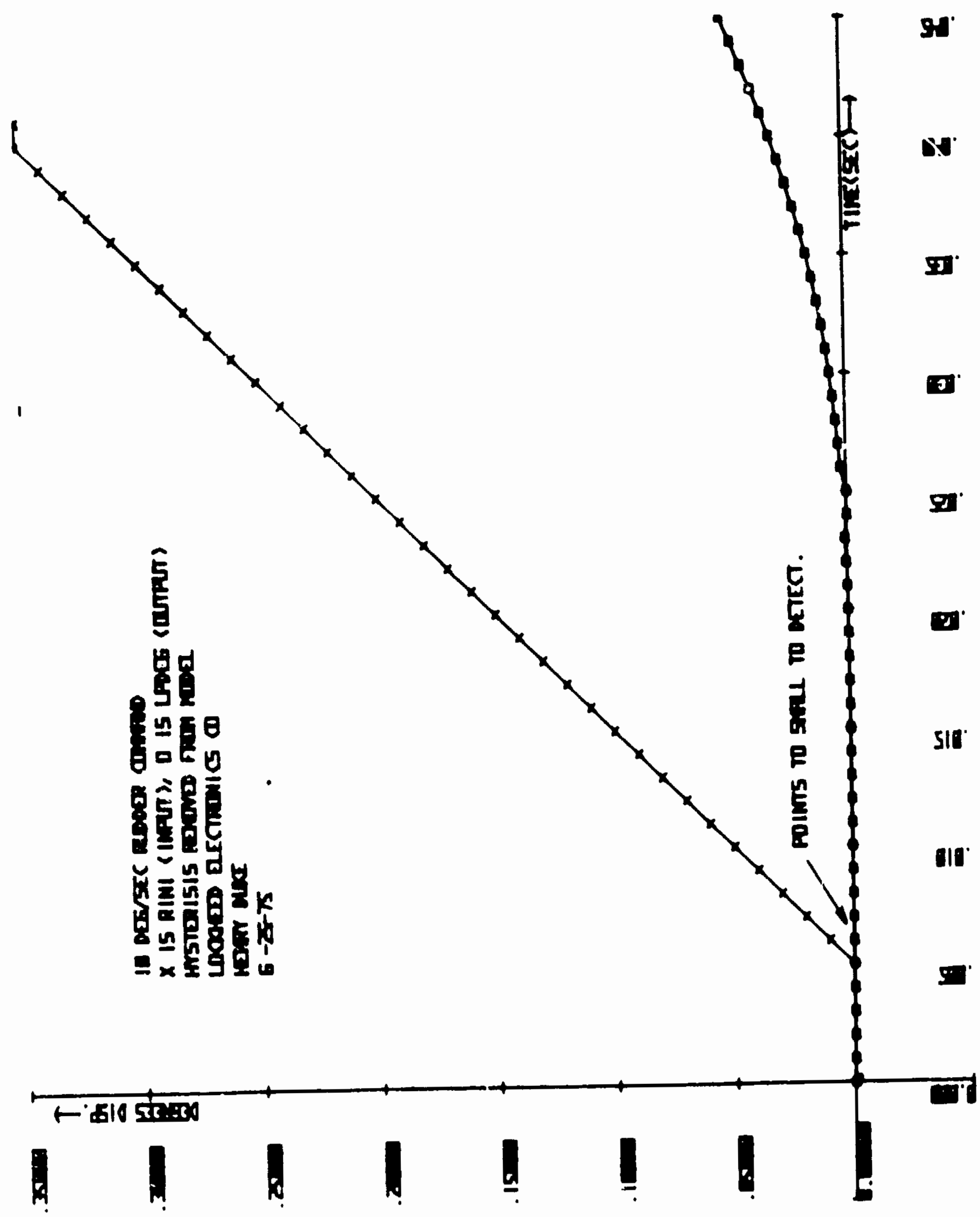


Figure 6-5. — Input stimulus and output response without hysteresis.

TABLE VI.– RUDDER DEADSPACE FOR SERVO FLAPPER VALVE

Ramp Input Command (deg/sec)	Start Time for Output of Flapper (sec)	Delay in Action through Servo Flapper (sec)
0.1	1.3815	1.3765
0.2	0.6932	0.6882
0.3	0.4638	0.4588
0.5	0.2803	0.2753
1.0	0.1427	0.1377
2.0	0.0738	0.0688
3.0	0.0509	0.0459
4.0	0.0394	0.0344
5.0	0.0325	0.0275
6.0	0.0279	0.0229
7.0	0.0247	0.1967
8.0	0.0222	0.0172
9.0	0.0202	0.0152
10.0	0.0187	0.0137
12.1	0.0164	0.0114

TABLE VII.– SPEEDBRAKE DEADSPACE FOR SERVO FLAPPER VALVE

Ramp Input	Delay in Servo Performance (Sec)	Actual Delay
0.1	2.5099	2.5049
0.2	1.2570	1.2520
0.3	0.8397	0.9835
0.5	0.5058	0.5008
0.7	0.3627	0.3577
1.0	0.2554	0.2504
2.0	0.1302	0.1252
3.0	0.0885	0.0835
4.0	0.0676	0.0626
5.0	0.0551	0.0501
6.1	0.0461	0.0411
8.0	0.0363	0.0313
10.84	0.0281	0.0231
12.0	0.0259	0.0209

6-5 does not fully demonstrate this, the CSMP readout began listing points for the output LPDEG at t = 5 ms, the start time for the input.

Some discrepancies do exist in the application of figures 6-3 and 6-4 beyond the 0.02 in-lb threshold. At this point, the secondary delta P feedback is no longer zero and therefore, begins to subtract from the input. The graph will therefore begin to change slope as the error begins to go to zero.

The values given in tables VI and VII were not graphically obtained but were mathematically calculated using the HP 9820. Consequently, they are more accurate than any values obtained from figures 6-3 and 6-4.

It must, therefore, be concluded from the information given that the hysteresis, and <u>only</u> the hysteresis, is the sole contributor to the deadspace.

7. CONCLUSIONS AND RECOMMENDATIONS

The contents of this report were concerned with the analysis of the Space Shuttle R/SB subsystem using the CSMP program to test the Rockwell math model contained in Rockwell publication SD 74-SH-0324.

It was first shown how the program was implimented using the CSMP technique and some performance limitations were given in using CSMP. A brief overlay of the CSMP program technique was made with a sample program and glossary appearing in the appendix.

The report discussed three (3) separate areas of system performance: 1) the Step Response, 2) the Ramp Response, and 3) the delay time obtained in system response.

The Step Response was used to determine three (3) factors: 1) the linearity of the system, 2) the accuracy of the system, and 3) the speed of the system in responding to a step command. A 5-, 10- and 15-degree step command was separately addressed to first the Rudder and then to the Speedbrake. When one channel was exercised, the other was set to zero degree step input or null.

It was found that the Rudder displayed a 1-percent accurate output response for all three commands, whereas the Speedbrake response was in excess of 6 percent. The cause of this radical variation in accuracy was undetermined. It possibly exists in a definition of either the expected panel response to a 5-volt command not being 49.3 degrees RHL or in some factor in the summing and mixing gear trains. Further investigation will be necessary in this area to pinpoint the possible cause of trouble. The linearity of the Rudder was acceptable but the Speedbrake once again remained unacceptable. This was, however, probably caused by the run being too short to produce a true steady-state output response condition.

The 5-degree run was successful, but the 10-degree run may require more time. Since both Rudder and Speedbrake channels are identical except for constants, this appears to be the only reasonable solution. It was also found that both the Rudder and Speedbrake would be hardware capable of meeting maximum software input commands.

It was found that a low level oscillation exists in step command response. But it was such a low level that it is thought to be insignificant for further study. Further testing will require an observation of the oscillation but, unless it becomes significant, it will probably be neglected in future reports.

The ramp response was used to determine two factors: 1) the tracking ability and 2) the ability of the hydraulic system to meet specifications. The system was found to track very close to input command, in fact, with an undetectable error in both Rudder and Speedbrake performance. Oscillation was found to be virtually nonexistant and undetectable in output response. The speed of the hydraulic motors was compared with Rockwell-furnished data and found to be extremely accurate for the Rudder and within 3 percent for the Speedbrake. The hydraulic flow into the motors was compared with the maximum possible flow from the hydraulic pumps and it was found that the motors would not overstress the system for normal operation. Abnormal operating characteristics, such as the failure of one or two motors, will be the subject of a Failure Modes and Effects Analysis to be commenced soon.

The final section of the report dealt with one of the nonlinearities of the system; namely, the results of the system hysteresis. It was found that the system response was delayed from the input by a large period of time. An investigation was launched into the causes of this phenomena and the severity of its occurance. It was found that the cause was solely the hysteresis loops contained within the model. The severity of the phenomena remains unknown since there appears to be no gauge as to its magnitude. The

Rudder was found to exhibit a delay time (or deadspace as it is called in this report) of 75 milliseconds whereas the Speedbrake was in excess of 200 milliseconds. The Rudder input rate was 10 deg/sec whereas the Speedbrake was 6 deg/sec. It was further found that, because the hysteresis loops created a threshold which had to be surpassed, the deadspace was command-dependent. An approximate mathematical technique has been developed in this report to determine the deadspace for all possible input commands.

This report leaves several unanswered questions. The most prominent of these is the large steady-state error in Speedbrake performance. Since the Speedbrake involves the use of both panels separating in opposite directions, it is conceivable that the observed error could be twice that of the Rudder. This does not, however, appear to be the case since the error is in excess of 6 percent. This issue needs to be persued in greater depth.

Another item of interest is the large deadspace observed in both Rudder and Speedbrake output responses. This, as was observed, was solely the contribution of the hysteresis contained in the system and not some other ambiguous factor. At present, there appears to be no specification to cover this problem.

Future runs need to focus on these two items in particular, especially linearity. Critical items such as changing ASA gain and panel load factors will continue to create new runs to determine response to design changes and/or modifications of parameters. A failure Modes and Effects Analysis is also scheduled. During this study, the output response caused by such failures as failing a single motor will be observed.

The results herein will be used as guidelines, when possible, in the design of a R/SB subsystem hardware model. However, since the system is very fluid at the present time, the information contained herein will probably change with the hardware model following the latest designs.

8. REFERENCES

1. Anon.: Descriptions and Mathematical Models for Aerosurface Actuators. Rockwell International, Space Division, SD 74-SH-0324, December 1974.

2. Anon.: Continuous System Modeling Program III (CSMP III). IBM, SH 19-7001-2, September 1972.

3. Anon.: Procurement Specification, Actuator Subsystem, Rudder/Speedbrake. Rockwell International, Space Division; MC621-0053, February 1975.

4. Merrit, Herbert E.: Hydraulic Control Systems. John Wiley & Sons, Inc., 1967.

5. Gibson, J. E., et.al.: A Set of Standard Specifications for Linear Automatic Control Systems. AIEE Transactions, May 1961.

APPENDIX A

SAMPLE PRINTOUT
OF
CSMP

```
//HD01NASA JOB (1234),'H DUKE',TIME=40 ,MSGLEVEL=(0,0)
//CSMPT PROC DSYS=2314,LIBRARY='CSMP.LIBRARY.SYSTEM',
//             PRELOAD='CSMP.LOAD.',STEPLIB=SYSTEM,VSYS=SYSAUX
//T   EXEC   PGM=DEJCSMP5,REGION=102K,TIME=10
//CSMPLIB DD UNIT=&DSYS,VOL=SER=&VSYS,DISP=SHR,DSN=&LIBRARY
//FT01F001 DD UNIT=SYSDA,SPACE=(3500,(20,20)),DSN=&&SYSIN,
//             DCB=(RECFM=FB,LRECL=80,BLKSIZE=800)
//FT02F001 DD SYSOUT=B,DCB=(RECFM=F,BLKSIZE=80)
//FT05F001 DD UNIT=SYSDA,SPACE=(3500,(10,10)),
//            DCB=(RECFM=F,BLKSIZE=80),DISP=(NEW,PASS)
//FT07F001 DD UNIT=SYSDA,SPACE=(3500,(20,20)),
//            DCB=(RECFM=F,BLKSIZE=80),DISP=(NEW,PASS)
//FT13F001 DD UNIT=SYSDA,SPACE=(3500,(40,40)),
//            DCB=(RECFM=VS,BLKSIZE=444)
//FT14F001 DD UNIT=SYSDA,SPACE=(3500,(10,10)),DCB=(RECFM=F,BLKSIZE=80)
//STEPLIB DD UNIT=&DSYS,VOL=SER=&VSYS,DISP=(SHR,PASS),
//         DSN=&PRELOAD&STEPLIB
//FT03F001   DD   SYSOUT=A
//FT08F001 DD SYSOUT=A,DCB=(RECFM=FBA,LRECL=133,BLKSIZE=1330)
//FT06F001 DD SYSOUT=A,DCB=(RECFM=FBA,LRECL=133,BLKSIZE=1330)
//        PEND   CSMPT
//TRANS   EXEC   CSMPT
++CSMPT PROC DSYS=2314,LIBRARY='CSMP.LIBRARY.SYSTEM',
++             PRELOAD='CSMP.LOAD.',STEPLIB=SYSTEM,VSYS=SYSAUX
++T   EXEC   PGM=DEJCSMP5,REGION=102K,TIME=10
++CSMPLIB DD UNIT=&DSYS,VOL=SER=&VSYS,DISP=SHR,DSN=&LIBRARY
IEF653I SUBSTITUTION JCL - UNIT=2314,VOL=SER=SYSAUX,DISP=SHR,DSN=CSMP.LIBRARY.SYSTEM
++FT01F001 DD UNIT=SYSDA,SPACE=(3500,(20,20)),DSN=&&SYSIN,
++             DCB=(RECFM=FB,LRECL=80,BLKSIZE=800)
++FT02F001 DD SYSOUT=B,DCB=(RECFM=F,BLKSIZE=80)
++FT05F001 DD UNIT=SYSDA,SPACE=(3500,(10,10)),
++            DCB=(RECFM=F,BLKSIZE=80),DISP=(NEW,PASS)
++FT07F001 DD UNIT=SYSDA,SPACE=(3500,(20,20)),
++            DCB=(RECFM=F,BLKSIZE=80),DISP=(NEW,PASS)
++FT13F001 DD UNIT=SYSDA,SPACE=(3500,(40,40)),
++            DCB=(RECFM=VS,BLKSIZE=444)
++FT14F001 DD UNIT=SYSDA,SPACE=(3500,(10,10)),DCB=(RECFM=F,BLKSIZE=80)
++STEPLIB DD UNIT=&DSYS,VOL=SER=&VSYS,DISP=(SHR,PASS),
IEF653I SUBSTITUTION JCL - UNIT=2314,VOL=SER=SYSAUX,DISP=(SHR,PASS),
++         DSN=&PRELOAD&STEPLIB
IEF653I SUBSTITUTION JCL - DSN=CSMP.LOAD.SYSTEM
++FT03F001   DD   SYSOUT=A
++FT08F001 DD SYSOUT=A,DCB=(RECFM=FBA,LRECL=133,BLKSIZE=1330)
++FT06F001 DD SYSOUT=A,DCB=(RECFM=FBA,LRECL=133,BLKSIZE=1330)
//T.SYSIN DD *
IEF236I ALLOC. FOR HD01NASA T          TRANS
IEF237I 134    ALLOCATED TO CSMPLIB
IEF237I 133    ALLOCATED TO FT01F001
IEF237I 133    ALLOCATED TO FT02F001
IEF237I 134    ALLOCATED TO FT05F001
IEF237I 133    ALLOCATED TO FT07F001
IEF237I 134    ALLOCATED TO FT13F001
IEF237I 133    ALLOCATED TO FT14F001
IEF237I 134    ALLOCATED TO STEPLIB
IEF237I 134    ALLOCATED TO FT03F001
IEF237I 133    ALLOCATED TO FT08F001
IEF237I 134    ALLOCATED TO FT06F001
IEF237I 133    ALLOCATED TO SYSIN
```

```
$$$CONTINUOUS SYSTEM MODELING PROGRAM   III   V1M2   TRANSLATOR OUTPUTS$$

*********************************************************************
TITLE RUDDER RUN 10 DEG/SEC COMMAND                         TP 6.2C.75
*THE FOLLOWING LISTING CORRESPONDS TO A SPECIAL LISTING FOR
*RUDDER7SPEEDBRAKE ANALYSIS
*********************************************************************
*
*              CARD INDEX
*
*     CARD NUMBER          REPRESENTS
*          1               JOB CARD
*          2               INPUT JCL
*         24               INDEX CARDS
*         25               INITIAL
*         71               DYNAMIC
*        581               TERMINAL
*        629               OUTPUT JCL
*
*
INITIAL
MACRO TF=RUDTOR(TOLP,RP,RATE,G1,G2,G3,EFF)
PROCEDURAL
      X1=SIGN(1.0,TOLP)
      X2=SIGN(1.0,RATE)
      IF((X1.GT.0.0).AND.(X2.GT.0.0)) GO TO 10
      IF((X1.LT.0.0).AND.(X2.LT.0.0)) GO TO 10
      IF(X1.NE.X2) GO TO 40
   10 TF=(TOLP+RP)*EFF/(3*G1*G2*G3)
      GO TO 50
   40 TF=(TOLP+RP)/(3*G1*G2*G3*EFF)
   50 CONTINUE
ENDMACRO
MACRO SBTF=SBTOR(SLP,SRP,SRATE,SG1,SG2,SG3,SEFF)
PROCEDURAL
      X1=SIGN(1.0,SLP)
      X2=SIGN(1.0,SRATE)
      IF((X1.GT.0.0).AND.(X2.GT.0.0)) GO TO 15
      IF((X1.LT.0.0).AND.(X2.LT.0.0)) GO TO 15
      IF(X1.NE.X2) GO TO 25
   15 SBTF=(SLP-SRP)*SEFF/(3*SG1*SG2*SG3)
      GO TO 35
   25 SBTF=(SLP-SRP)/(3*SG1*SG2*SG3*SEFF)
   35 CONTINUE
ENDMACRO
* 50-------------------------------------------------------------------
FUNCTION HINGE = (-49.3,1.025E6),(0,0),(49.3,-1.025E6)
*RSLP  = SLOPE OF INPUT FUNCTION
CONST RSLP1=10.0,RSLP2=10.0,RSLP3=10.0,RSLP4=10.0
*SBSLP = SLOPE OF INPUT FUNCTION
CONST SBSLP1=0.0,SBSLP2=0.0,SBSLP3=0.0,SBSLP4=0.0
CONST IC=0.0
CONST MR=0.00207,BR=1.3860,XRM=0.065,DELTX3=0.0,DELTX2=0.0,...
      KB=0.52,PS1=2800.0,PS2=2800.0,PS3=2800.0,KQP=33.2,...
      BETA=1.8E5,VM=3.88,KPO=0.004,TC=9.0,JMR=0.00636,JMS=0.00565,...
      BM=0.015,GS=7.32,GMR=1.47,GMS=4.46,...
      GH=473.921,JP=2579.0,BPP=15500.0,TPC=0.0,IL=8.0,DELTX1=0.0
CONST AC=0.008975,AP=0.0276,AS=0.193,BP=0.0648,C1=185.2,C2=0.1056,...
      C3=8.76E-5,CP=5.03E-5,CQ=4.5866,KFBL=6.22,KP=1200.0,...
      KN=1.38E-4,KTM=0.045,MP=6.83E-5,LN=0.01693,VT=0.0838,...
```

```
         VT2=0.62,X0=0.00185,RPS=2800.0,SPS=2800.0,TAUC=0.1,KAMP=17.5,...
         WD=314.0,LD=0.707,TDT=0.004,KPT=0.00167,KFB=10.571177,KC=1.51617
CONST  Y1=1.0,Y2=1.0,Z1=1.0,Z2=1.0
CONST  KSB=0.88438,KR=0.841328,RAD=57.29578,KFBSB=5.81093,KRV=0.1845,...
         KSBV=0.10142
CONST  HS=0.0476475,HMR=0.02088577,HMSB=0.02088577,HH=2.9088E-3
CONST  DSBX3=0.0,DSBX2=0.0,DSBX1=0.0
CONST  XSM=0.065,D=0.08276,EG=0.7872,FRC=13.0
CONST  KHC=0.397E8,KHST=0.02,KFL=0.0011
CONST  CCNV=0.2527
*CONVERT FROM RADIANS/SEC TO RPM
CONST  CRPM = 9.5492966
         CONST  C1=0.0, IC2=0.0
DYNAMIC
*RUDDER INPUT EQUATIONS FROM ASA ELECTRONICS
RIN1 = RSLP1*RAMP(0.005)
RIN2 = RSLP2*RAMP(0.005)
RIN3 = RSLP3*RAMP(0.005)
RIN4 = RSLP4*RAMP(0.005)
*SPEEDBRAKE INPUT EQUATIONS FROM ASA ELECTRONICS
SIN1 = SBSLP1*RAMP(0.005)
SIN2 = SBSLP2*RAMP(0.005)
SIN3 = SBSLP3*RAMP(0.005)
SIN4 = SBSLP4*RAMP(0.005)
*RUDDER EQUATIONS
         RVIN1=RIN1*KRV
         RVIN2=RIN2*KRV
         RVIN3=RIN3*KRV
         RVIN4=RIN4*KRV
         RASAI1=(RVIN1-RVZ1)*KAMP-RVK1
         RASAI2=(RVIN2-RVZ2)*KAMP-RVK2
         RASAI3=(RVIN3-RVZ3)*KAMP-RVK3
         RASAI4=(RVIN4-RVZ4)*KAMP-RVK4
         RIL1=LIMIT(-IL,IL,RASAI1)
*RUDDER SERVO(SECONDARY ACTUATOR) NO. 1
         RT1=RIL1*KTM
         RTIN1=HSTRSS(IC,-KHST,KHST,RT1)
         RFT1=RTIN1-RFP1*KN-XRL*KFBL
         RFX1=RFT1*LN
         RFXLM1=LIMIT(-KFL,KFL,RFX1)
         RF1FLW=(2.0*C1*RFXLM1)-(2.0*(AP-AC)*DERIV(IC,RXSS1))
         DR1X1=RF1FLW-(R1X1*G1/G2)
         R1X1=INTGRL(IC,DR1X1)
         RFP1=R1X1/G2
         G1=C3+C2*X0
         G2=VT2/(2.0*BETA)
         RF1FT=RFP1*(AP-AC)-RSAP1*AC
*100--------------------------------------------------------------------100
         RDDSP1=RF1FT-(RDSP1*(BP/MP))-(RSP1*(KP/MP))
         RDSP1=INTGRL(IC,RDDSP1)
         RSP1=INTGRL(IC,RDSP1)
         RXSS1=RSP1/MP
         RPVS1=RPS-(RSAP1*SIGN(1.0,RXSS1))
         R1Q0=CQ*RXSS1*SIGN(1.0,RPVS1)*SQRT(ABS(RPVS1))
         RQXSA1=R1Q0+AP*DERIV(IC,RXSS1)
         RDXSA1=(RQXSA1-(RSAP1*CP))/AS
         RXSA1=INTGRL(IC,RDXSA1)
         RXA1=RXSA1-XRL
         RSAP1=RXA1*((4.0*BETA*AS)/VT2)
```

```
      RF1=RSAP1*AS
      RIL2=LIMIT(-IL,IL,RASAI2)
*RUDDER SERVO(SECONDARY ACTUATOR) NO. 2
      RT2=RIL2*KTM
      RTIN2=HSTRSS(IC,-KHST,KHST,RT2)
      RFT2=RTIN2-RFP2*KN-XRL*KFBL
      RFX2=RFT2*LN
      RFXLM2=LIMIT(-KFL,KFL,RFX2)
      RF2FLW=(2.0*C1*RFXLM2)-(2.0*(AP-AC)*DERIV(IC,RXSS2))
      DR2X1=RF2FLW-(R2X1*G1/G2)
      R2X1=INTGRL(IC,DR2X1)
      RFP2= R2X1/G2
      RF2FT=RFP2*(AP-AC)-RSAP2*AC
      RDDSP2=RF2FT-(RDSP2*(BP/MP))-(RSP2*(KP/MP))
      RDSP2=INTGRL(IC,RDDSP2)
      RSP2=INTGRL(IC,RDSP2)
      RXSS2=RSP2/MP
      RPVS2=RPS-(RSAP2*SIGN(1.0,RXSS2))
      R2Q0=CQ*RXSS2*SIGN(1.0,RPVS2)*SQRT(ABS(RPVS2))
      RQXSA2=R2Q0+AP*DERIV(IC,RXSS2)
      RDXSA2=(RQXSA2-(RSAP2*CP))/AS
      RXSA2=INTGRL(IC,RDXSA2)
      RXA2=RXSA2-XRL
      RSAP2=RXA2*((4.0*BETA*AS)/VT2)
      RF2=RSAP2*AS
      RIL3=LIMIT(-IL,IL,RASAI3)
*RUDDER SERVO(SECONDARY ACTUATOR) NO. 3
      RT3=RIL3*KTM
      RTIN3=HSTRSS(IC,-KHST,KHST,RT3)
      RFT3=RTIN3-RFP3*KN-XRL*KFBL
      RFX3=RFT3*LN
      RFXLM3=LIMIT(-KFL,KFL,RFX3)
      RF3FLW=(2.0*C1*RFXLM3)-(2.0*(AP-AC)*DERIV(IC,RXSS3))
      DR3X1=RF3FLW-(R3X1*G1/G2)
      R3X1=INTGRL(IC,DR3X1)
      RFP3= R3X1/G2
      RF3FT=RFP3*(AP-AC)-RSAP3*AC
      RDDSP3=RF3FT-(RDSP3*(BP/MP))-(RSP3*(KP/MP))
      RDSP3=INTGRL(IC,RDDSP3)
      RSP3=INTGRL(IC,RDSP3)
      RXSS3=RSP3/MP
*150-----------------------------------------------------------------150
      RPVS3=RPS-(RSAP3*SIGN(1.0,RXSS3))
      R3Q0=CQ*RXSS3*SIGN(1.0,RPVS3)*SQRT(ABS(RPVS3))
      RQXSA3=R3Q0+AP*DERIV(IC,RXSS3)
      RDXSA3=(RQXSA3-(RSAP3*CP))/AS
      RXSA3=INTGRL(IC,RDXSA3)
      RXA3=RXSA3-XRL
      RSAP3=RXA3*((4.0*BETA*AS)/VT2)
      RF3=RSAP3*AS
      RIL4=LIMIT(-IL,IL,RASAI4)
      RT4=RIL4*KTM
      RTIN4=HSTRSS(IC,-KHST,KHST,RT4)
      RFT4=RTIN4-RFP4*KN-XRL*KFBL
      RFX4=RFT4*LN
      RFXLM4=LIMIT(-KFL,KFL,RFX4)
      RF4FLW=(2.0*C1*RFXLM4)-(2.0*(AP-AC)*DERIV(IC,RXSS4))
      DR4X1=RF4FLW-(R4X1*G1/G2)
      R4X1=INTGRL(IC,DR4X1)
```

```
         RFP4=R4X1/G2
         RF4FT=RFP4*(AP-AC)-RSAP4*AC
         RDDSP4=RF4FT-(RDSP4*(BP/MP))-(RSP4*(KP/MP))
         RDSP4=INTGRL(IC,RDDSP4)
         RSP4=INTGRL(IC,RDSP4)
         RXSS4=RSP4/MP
         RPVS4=RPS-(RSAP4*SIGN(1.0,RXSS4))
         R4QO=CQ*RXSS4*SIGN(1.0,RPVS4)*SQRT(ABS(RPVS4))
         RQXSA4=R4QO+AP*DERIV(IC,RXSS4)
         RDXSA4=(RQXSA4-(RSAP4*CP))/AS
         RXSA4=INTGRL(IC,RDXSA4)
         RXA4=RXSA4-XRL
         RSAP4=RXA4*((4.0*BETA*AS)/VT2)
         RF4=RSAP4*AS
         FRTOT=RF1+RF2+RF3+RF4
         FR=FRTOT-RBF-RSVFF
         RSVFF=FCNSW(  XRDOT,-FRC,0.0,FRC)
         XRDDOT=(FR-XRDFB)*Y2
         XRDFB=XRD*(BR/MR)
         XRD=INTGRL(IC,XRDDOT)
         XRDOT=(XRD/MR)*Y1
          XR=INTGRL(IC, XRDOOT)
         XRL=LIMIT(-XRM,XRM, XR)
PROCEDURE Y1,Y2=RRATE(XR,XRM)
         YY1=COMPAR(XR,XRM)
         IF (YY1.LT.1.0)GO TC 20
         Y1=0.0
         Y2=0.0
         GO TO 90
    20   Y1=1.0
         Y2=1.0
         YY2=COMPAR(XR,-XRM)
         IF(YY2.GT.0.0)GO TO 80
*200------------------------------------------------------------------------------------- 00
         Y1=0.0
         Y2=0.0
         GO TO 90
    80   Y2=1.0
         Y1=1.0
    90   CCNTINUE
END PROCEDURE
         RX3=XRL+DELTX3
         RX2=XRL+DELTX2
         RX1=XRL+DELTX1
         PV3=PS3-SIGN(1.0,RX3)*PL3LIM
         PV2=PS2-SIGN(1.0,RX2)*PL2LIM
         PV1=PS1-SIGN(1.0,RX1)*PL1LIM
         RBF3=PV3*RX3*KB
         RBF2=PV2*RX2*KB
         RBF1=PV1*RX1*KB
         RBF=RBF3+RBF2+RBF1
         QL3=KQP*SIGN(1.0,PV3)*SQRT(ABS(PV3))*RX3
         QL3GPM = CONV*QL3
         QL2=KQP*SIGN(1.0,PV2)*SQRT(ABS(PV2))*RX2
         QL2GPM = CONV*QL2
         QL1=KQP*SIGN(1.0,PV1)*SQRT(ABS(PV1))*RX1
         QL1GPM = CONV*QL1
         RSVMI3=QL3-(KPQ*PL3LIM)-(D*THDOT3)
         RSVMI2=QL2-(KPQ*PL2LIM)-(D*THDOT2)
```

```
      RSVMI1=QL1-(KPQ*PL1LIM)-(D*THDOT1)
      RSVI3=INTGRL(IC,RSVMI3)
      RSVI2=INTGRL(IC,RSVMI2)
      RSVI1=INTGRL(IC,RSVMI1)
      PL3=(4.0*BETA*RSVI3)/VM
      PL2=(4.0*BETA*RSVI2)/VM
      PL1=(4.0*BETA*RSVI1)/VM
      PL3LIM=LIMIT(-PS3,PS3,PL3)
      PL2LIM=LIMIT(-PS2,PS2,PL2)
      PL1LIM=LIMIT(-PS1,PS1,PL1)
*RUDDER MOTOR 3
      RMIN3=PL3LIM*D
      RTF3=RUDTOR(TLP,TRP,THDOT3,GH,GMR,GS,EG)
      RMSUM1=RTSW3-RTF3
      RTSW3=FCNSW(THDOT3,-TC,0.0,TC)
      RMSUM2=RMSUM1+(THDOT3*BM)
      THD3=(RMIN3-RMSUM2)/JMR
      THDOT3=INTGRL(IC,THD3)
      RTHET3=INTGRL(IC,THDOT3)
*RUDDER MOTOR 2
      RMIN2=PL2LIM*D
      RTF2=RUDTOR(TLP,TRP,THDOT2,GH,GMR,GS,EG)
      RMSUM3=RTSW2-RTF2
      RTSW2=FCNSW(THDOT2,-TC,0.0,TC)
      RMSUM4=RMSUM3+(THDOT2*BM)
      THD2=(RMIN2-RMSUM4)/JMR
      THDOT2=INTGRL(IC,THD2)
      RTHET2=INTGRL(IC,THDOT2)
*RUDDER MOTOR 1
      RMIN1=PL1LIM*D
      RTF1=RUDTOR(TLP,TRP,THDOT1,GH,GMR,GS,EG)
*250-----------------------------------------------------------------------250
      RMSUM5=RTSW1-RTF1
      RTSW1=FCNSW(THDOT1,-TC,0.0,TC)
      RMSUM6=RMSUM5+(THDOT1*BM)
      THD1=(RMIN1-RMSUM6)/JMR
      THDOT1=INTGRL(IC,THD1)
      RTHET1=INTGRL(IC,THDOT1)
*CONVERT FROM RADIANS/SEC TO RPM
      RM1RPM = CRPM*THDOT1
      RM2RPM = CRPM*THDOT2
      RM3RPM = CRPM*THDOT3
*RUDDER MECHANICAL SUMMING DIFFERENTIALS
      DELTR1=RTHET1/GS
      DELTR2=RTHET2/GS
      DELTR3=RTHET3/GS
      RUDSUM=DELTR3+DELTR2+DELTR1
      DELTR=HSTRSS(IC,-HS,HS,RUDSUM)
      RUDFB=DELTR/(GMR*GH)
      DRVL1= RSAP1*(KPT/TDT)-RVL1/TDT
      RVL1=INTGRL(IC,DRVL1)
      RDDVW1=RVL1-(RDVW1*(2.0*LD*WD))-RVW1
      RDVW1=INTGRL(IC,RDDVW1)
      RVW1=(WD*WD)*INTGRL(IC,RDVW1)
      RDVK1=KC*DERIV(IC,RVW1)
      RDVKI1=RDVK1-(RVK1/TAUC)
      RVK1=INTGRL(IC,RDVKI1)
      RLV1=RUDFB*(KFB/TDT)-RLVOT1/TDT
      RLVOT1=INTGRL(IC,RLV1)
```

```
      RDDVZ1=RLVDT1-(RDVZ1*(2.0*LD*WD))-RVZ1
      RDVZ1=INTGRL(IC,RDDVZ1)
      RVZ1=(WD*WD)*INTGRL(IC,RDVZ1)
      DRVL2=RSAP2*(KPT/TDT)-RVL2/TDT
      RVL2=INTGRL(IC,DRVL2)
      RDDVW2=RVL2-(RDVW2*(2.0*LD*WD))-RVW2
      RDVW2=INTGRL(IC,RDDVW2)
      RVW2=(WD*WD)*INTGRL(IC,RDVW2)
      RDVK2=KC*DERIV(IC,RVW2)
      RDVKI2=RDVK2-(RVK2/TAUC)
      RVK2=INTGRL(IC,RDVKI2)
      RLV2=RUDFB*(KFB/TDT)-RLVDT2/TDT
      RLVDT2=INTGRL(IC,RLV2)
      RDDVZ2=RLVDT2-(RDVZ2*(2.0*LD*WD))-RVZ2
      RDVZ2=INTGRL(IC,RDDVZ2)
      RVZ2=(WD*WD)*INTGRL(IC,RDVZ2)
      DRVL3=RSAP3*(KPT/TDT)-RVL3/TDT
      RVL3=INTGRL(IC,DRVL3)
      RDDVW3=RVL3-(RDVW3*(2.0*LD*WD))-RVW3
      RDVW3=INTGRL(IC,RDDVW3)
      RVW3=(WD*WD)*INTGRL(IC,RDVW3)
      RDVK3=KC*DERIV(IC,RVW3)
      RDVKI3=RDVK3-(RVK3/TAUC)
      RVK3=INTGRL(IC,RDVKI3)
      RLV3=RUDFB*(KFB/TDT)-RLVDT3/TDT
      RLVDT3=INTGRL(IC,RLV3)
      RDDVZ3=RLVDT3-(RDVZ3*(2.0*LD*WD))-RVZ3
      RDVZ3=INTGRL(IC,RDDVZ3)
*300------------------------------------------------------------300
      RVZ3=(WD*WD)*INTGRL(IC,RDVZ3)
      DRVL4=RSAP4*(KPT/TDT)-RVL4/TDT
      RVL4=INTGRL(IC,DRVL4)
      RDDVW4=RVL4-(RDVW4*(2.0*LD*WD))-RVW4
      RDVW4=INTGRL(IC,RDDVW4)
      RVW4=(WD*WD)*INTGRL(IC,RDVW4)
      RDVK4=KC*DERIV(IC,RVW4)
      RDVKI4=RDVK4-(RVK4/TAUC)
      RVK4=INTGRL(IC,RDVKI4)
      RLV4=RUDFB*(KFB/TDT)-RLVDT4/TDT
      RLVDT4=INTGRL(IC,RLV4)
      RDDVZ4=RLVDT4-(RDVZ4*(2.0*LD*WD))-RVZ4
      RDVZ4=INTGRL(IC,RDDVZ4)
      RVZ4=(WD*WD)*INTGRL(IC,RDVZ4)
*SPEEDBRAKE EQUATIONS
      SVIN1=SIN1*KSBV
      SVIN2=SIN2*KSBV
      SVIN3=SIN3*KSBV
      SVIN4=SIN4*KSBV
      SASAI1=(SVIN1-SVZ1)*KAMP-SVK1
      SASAI2=(SVIN2-SVZ2)*KAMP-SVK2
      SASAI3=(SVIN3-SVZ3)*KAMP-SVK3
      SASAI4=(SVIN4-SVZ4)*KAMP-SVK4
      SIL1=LIMIT(-IL,IL,SASAI1)
*SPEEDBRAKE SERVO(SECONDARY ACTUATOR) NO. 1
      ST1=SIL1*KTM
      STMN1=HSTRSS(IC,-KMST,KMST,ST1)
      SFT1=STMN1-SFP1*KN-XSL*KFBL
      SFX1=SFT1*LN
      SFXLM1=LIMIT(-KFL,KFL,SFX1)
```

```
      SF1FLW=(2.0*C1*SFXLM1)-(2.0*(AP-AC)*DERIV(IC,SXSS1))
      DS1X1=SF1FLW-(S1X1*G1/G2)
      S1X1=INTGRL(IC,DS1X1)
      SFP1=S1X1/G2
      SF1FT=SFP1*(AP-AC)-SSAP1*AC
      SDDSP1=SF1FT-(SDSP1*(BP/MP))-(SSP1*(KP/MP))
      SDSP1=INTGRL(IC,SDDSP1)
      SSP1=INTGRL(IC,SDSP1)
      SXSS1=SSP1/MP
      SPVS1=SPS-(SSAP1*SIGN(1.0,SXSS1))
      S1QO=CQ*SXSS1*SIGN(1.0,SPVS1)*SQRT(ABS(SPVS1))
      SQXSA1=S1QO+AP*DERIV(IC,SXSS1)
      SDXSA1=(SQXSA1-(SSAP1*CP))/AS
      SXSA1=INTGRL(IC,SDXSA1)
      SXA1=SXSA1-XSL
      SSAP1=SXA1*((4.0*BETA*AS)/VT2)
      SF1=SSAP1*AS
      SIL2=LIMIT(-IL,IL,SASAI2)
*SPEEDBRAKE SERVO(SECONDARY ACTUATOR) NO. 2
      ST2=SIL2*KTM
      STIN2=HSTRSS(IC,-KHST,KHST,ST2)
      SFT2=STIN2-SFP2*KN-XSL*KFBL
      SFX2=SFT2*LN
*350 --------------------------------------------------------------------350
      SFXLM2=LIMIT(-KFL,KFL,SFX2)
      SF2FLW=(2.0*C1*SFXLM2)-(2.0*(AP-AC)*DERIV(IC,SXSS2))
      DS2X1=SF2FLW-(S2X1*G1/G2)
      S2X1=INTGRL(IC,DS2X1)
      SFP2=S2X1/G2
      SF2FT=SFP2*(AP-AC)-SSAP2*AC
      SDDSP2=SF2FT-(SDSP2*(BP/MP))-(SSP2*(KP/MP))
      SDSP2=INTGRL(IC,SDDSP2)
      SSP2=INTGRL(IC,SDSP2)
      SXSS2=SSP2/MP
      SPVS2=SPS-(SSAP2*SIGN(1.0,SXSS2))
      S2QO=CQ*SXSS2*SIGN(1.0,SPVS2)*SQRT(ABS(SPVS2))
      SQXSA2=S2QO+AP*DERIV(IC,SXSS2)
      SDXSA2=(SQXSA2-(SSAP2*CP))/AS
      SXSA2=INTGRL(IC,SDXSA2)
      SXA2=SXSA2-XSL
      SSAP2=SXA2*((4.0*BETA*AS)/VT2)
      SF2=SSAP2*AS
      SIL3=LIMIT(-IL,IL,SASAI3)
*SPEEDBRAKE SERVO(SECONDARY ACTUATOR) NO. 3
      ST3=SIL3*KTM
      STIN3=HSTRSS(IC,-KHST,KHST,ST3)
      SFT3=STIN3-SFP3*KN-XSL*KFBL
      SFX3=SFT3*LN
      SFXLM3=LIMIT(-KFL,KFL,SFX3)
      SF3FLW=(2.0*C1*SFXLM3)-(2.0*(AP-AC)*DERIV(IC,SXSS3))
      DS3X1=SF3FLW-(S3X1*G1/G2)
      S3X1=INTGRL(IC,DS3X1)
      SFP3=S3X1/G2
      SF3FT=SFP3*(AP-AC)-SSAP3*AC
      SDDSP3=SF3FT-(SDSP3*(BP/MP))-(SSP3*(KP/MP))
      SDSP3=INTGRL(IC,SDDSP3)
      SSP3=INTGRL(IC,SDSP3)
      SXSS3=SSP3/MP
      SPVS3=SPS-(SSAP3*SIGN(1.0,SXSS3))
```

```
      S3QO=CQ*SXSS3*SIGN(1.0,SPVS3)*SQRT(ABS(SPVS3))
      SQXSA3=S3QO+AP*DERIV(IC,SXSS3)
      SDXSA3=(SQXSA3-(SSAP3*CP))/AS
      SXSA3=INTGRL(IC,SDXSA3)
      SXA3=SXSA3-XSL
      SSAP3=SXA3*((4.0*BETA*AS)/VT2)
      SF3=SSAP3*AS
      SIL4=LIMIT(-IL,IL,SASAI4)
      ST4=SIL4*KTM
      STIN4=HSTRSS(IC,-KHST,KHST,ST4)
      SFT4=STIN4-SFP4*KN-XSL*KFBL
      SFX4=SFT4*LN
      SFXLM4=LIMIT(-KFL,KFL,SFX4)
      SF4FLW=(2.0*C1*SFXLM4)-(2.0*(AP-AC)*DERIV(IC,SXSS4))
      DS4X1=SF4FLW-(S4X1*G1/G2)
      S4X1=INTGRL(IC,DS4X1)
*400-------------------------------------------------------------------400
      SFP4=S4X1/G2
      SF4FT=SFP4*(AP-AC)-SSAP4*AC
      SDDSP4=SF4FT-(SDSP4*(BP/MP))-(SSP4*(KP/MP))
      SDSP4=INTGRL(IC,SDDSP4)
      SSP4=INTGRL(IC,SDSP4)
      SXSS4=SSP4/MP
      SPVS4=SPS-(SSAP4*SIGN(1.0,SXSS4))
      S4QO=CQ*SXSS4*SIGN(1.0,SPVS4)*SQRT(ABS(SPVS4))
      SQXSA4=S4QO+AP*DERIV(IC,SXSS4)
      SDXSA4=(SQXSA4-(SSAP4*CP))/AS
      SXSA4=INTGRL(IC,SDXSA4)
      SXA4=SXSA4-XSL
      SSAP4=SXA4*((4.0*BETA*AS)/VT2)
      SF4=SSAP4*AS
      FSTOT=SF1+SF2+SF3+SF4
      FS=FSTOT-SBF-SSVFF
      SSVFF=FCNSW( XSDOT,-FRC,0.0,FRC)
      XSDDOT=(FS-XSDFB)*Z2
      XSDFB=XSD*(BR/MR)
      XSD=INTGRL(IC,XSDDOT)
      XSDOT=(XSD/MR)*Z1
       XS=INTGRL(IC, XSDOT)
      XSL=LIMIT(-XSM,XSM, XS)
PROCEDURE Z1,Z2=SRATE(XS,XSM)
      ZZ1=COMPAR(XS,XSM)
      IF (ZZ1.LT.0.0)GO TO 30
      Z1=0.0
      Z2=0.0
      GO TO 60
   30 Z1=1.0
      Z2=1.0
      ZZ2=COMPAR(XS,-XSM)
      IF(ZZ2.GT.0.0)GO TO 70
      Z1=0.0
      Z2=0.0
      GO TO 60
   70 Z2=1.0
      Z1=1.0
   60 CONTINUE
END PROCEDURE
      SX3=XSL+DSBX3
      SX2=XSL+DSBX2
```

```
      SX1=XSL+DSBX1
      SPV3=PS3-SIGN(1.0,SX3)*PSL3LM
      SPV2=PS2-SIGN(1.0,SX2)*PSL2LM
      SPV1=PS1-SIGN(1.0,SX1)*PSL1LM
      SBF3=SPV3*SX3*KB
      SBF2=SPV2*SX2*KB
      SBF1=SPV1*SX1*KB
      SBF=SBF3+SBF2+SBF1
*450---------------------------------------------------------------------------450
      QSL3=KQP*SIGN(1.0,SPV3)*SQRT(ABS(SPV3))*SX3
      QSL3GM = CONV*QSL3
      QSL2=KQP*SIGN(1.0,SPV2)*SQRT(ABS(SPV2))*SX2
      QSL2GM = CONV*QSL2
      QSL1=KQP*SIGN(1.0,SPV1)*SQRT(ABS(SPV1))*SX1
      QSL1GM = CONV*QSL1
      SSVMI3=QSL3-(KPQ*PSL3LM)-(D*THDTS3)
      SSVMI2=QSL2-(KPQ*PSL2LM)-(D*THDTS2)
      SSVMI1=QSL1-(KPQ*PSL1LM)-(D*THDTS1)
      SSVI1=INTGRL(IC,SSVMI1)
      SSVI2=INTGRL(IC,SSVMI2)
      SSVI3=INTGRL(IC,SSVMI3)
      PSL3=(4.0*BETA*SSVI3)/VM
      PSL2=(4.0*BETA*SSVI2)/VM
      PSL1=(4.0*BETA*SSVI1)/VM
      PSL3LM=LIMIT(-PS3,PS3,PSL3)
      PSL2LM=LIMIT(-PS2,PS2,PSL2)
      PSL1LM=LIMIT(-PS1,PS1,PSL1)
*SPEEDBRAKE MOTOR 3
      SMIN3=PSL3LM*D
      STF3=SBTOR(TLP,TRP,THDTS3,GH,GMS,GS,EG)
      SMSUM1=STSW3-STF3
      STSW3=FCNSW(THDTS3,-TC,0.0,TC)
      SMSUM2=SMSUM1+(THDTS3*BM)
      STHD3=(SMIN3-SMSUM2)/JMS
      THDTS3=INTGRL(IC,STHD3)
      STHET3=INTGRL(IC,THDTS3)
*SPEEDBRAKE MOTOR 2
      SMIN2=PSL2LM*D
      STF2=SBTOR(TLP,TRP,THDTS2,GH,GMS,GS,EG)
      SMSUM3=STSW2-STF2
      STSW2=FCNSW(THDTS2,-TC,0.0,TC)
      SMSUM4=SMSUM3+(THDTS2*BM)
      STHD2=(SMIN2-SMSUM4)/JMS
      THDTS2=INTGRL(IC,STHD2)
      STHET2=INTGRL(IC,THDTS2)
*SPEEDBRAKE MOTOR 1
      SMIN1=PSL1LM*D
      STF1=SBTOR(TLP,TRP,THDTS1,GH,GMS,GS,EG)
      SMSUM5=STSW1-STF1
      STSW1=FCNSW(THDTS1,-TC,0.0,TC)
      SMSUM6=SMSUM5+(THDTS1*BM)
      STHD1=(SMIN1-SMSUM6)/JMS
      THDTS1=INTGRL(IC,STHD1)
      STHET1=INTGRL(IC,THDTS1)
*CONVERT FROM RADIANS/SEC TO RPM
      SM1RPM = CRPM*THDTS1
      SM2RPM = CRPM*THDTS2
      SM3RPM = CRPM*THDTS3
*SPEEDBRAKE MECHANICAL SUMMING DIFFERENTIALS
```

```
      DELTS1=STHET1/GS
      DELTS2=STHET2/GS
      DELTS3=STHET3/GS
      SBSUM=DELTS3+DELTS2+DELTS1
      DELTSB=HSTRSS(IC,-HS,HS,SBSUM)
      SBFB=2.0*DELTSB/(GMS*GH)
      DSVL1=SSAP1*(KPT/TDT)-SVL1/TDT
      SVL1=INTGRL(IC,DSVL1)
      SDDVW1=SVL1-(SDVW1*(2.0*LD*WD))-SVW1
      SDVW1=INTGRL(IC,SDDVW1)
      SVW1=(WD*WD)*INTGRL(IC,SDVW1)
*500-----------------------------------------------------------------500
      SDVK1=KC*DERIV(IC,SVW1)
      SDVKI1=SDVK1-(SVKI/TAUC)
      SVK1=INTGRL(IC,SDVKI1)
      SLV1=SBFB*(KFBSB/TDT)-SLVDT1/TDT
      SLVDT1=INTGRL(IC,SLV1)
      SDDVZ1=SLVDT1-(SDVZ1*(2.0*LD*WD))-SVZ1
      SDVZ1=INTGRL(IC,SDDVZ1)
      SVZ1=(WD*WD)*INTGRL(IC,SDVZ1)
      DSVL2=SSAP2*(KPT/TDT)-SVL2/TDT
      SVL2=INTGRL(IC,DSVL2)
      SDDVW2=SVL2-(SDVW2*(2.0*LD*WD))-SVW2
      SDVW2=INTGRL(IC,SDDVW2)
      SVW2=(WD*WD)*INTGRL(IC,SDVW2)
      SDVK2=KC*DERIV(IC,SVW2)
      SDVKI2=SDVK2-(SVK2/TAUC)
      SVK2=INTGRL(IC,SDVKI2)
      SLV2=SBFB*(KFBSB/TDT)-SLVDT2/TDT
      SLVDT2=INTGRL(IC,SLV2)
      SDDVZ2=SLVDT2-(SDVZ2*(2.0*LD*WD))-SVZ2
      SDVZ2=INTGRL(IC,SDDVZ2)
      SVZ2=(WD*WD)*INTGRL(IC,SDVZ2)
      DSVL3=SSAP3*(KPT/TDT)-SVL3/TDT
      SVL3=INTGRL(IC,DSVL3)
      SDDVW3=SVL3-(SDVW3*(2.0*LD*WD))-SVW3
      SDVW3=INTGRL(IC,SDDVW3)
      SVW3=(WD*WD)*INTGRL(IC,SDVW3)
      SDVK3=KC*DERIV(IC,SVW3)
      SDVKI3=SDVK3-(SVK3/TAUC)
      SVK3=INTGRL(IC,SDVKI3)
      SLV3=SBFB*(KFBSB/TDT)-SLVDT3/TDT
      SLVDT3=INTGRL(IC,SLV3)
      SDDVZ3=SLVDT3-(SDVZ3*(2.0*LD*WD))-SVZ3
      SDVZ3=INTGRL(IC,SDDVZ3)
      SVZ3=(WD*WD)*INTGRL(IC,SDVZ3)
      DSVL4=SSAP4*(KPT/TDT)-SVL4/TDT
      SVL4=INTGRL(IC,DSVL4)
      SDDVW4=SVL4-(SDVW4*(2.0*LD*WD))-SVW4
      SDVW4=INTGRL(IC,SDDVW4)
      SVW4=(WD*WD)*INTGRL(IC,SDVW4)
      SDVK4=KC*DERIV(IC,SVW4)
      SDVKI4=SDVK4-(SVK4/TAUC)
      SVK4=INTGRL(IC,SDVKI4)
      SLV4=SBFB*(KFBSB/TDT)-SLVDT4/TDT
      SLVDT4=INTGRL(IC,SLV4)
      SDDVZ4=SLVDT4-(SDVZ4*(2.0*LD*WD))-SVZ4
      SDVZ4=INTGRL(IC,SDDVZ4)
      SVZ4=(WD*WD)*INTGRL(IC,SDVZ4)
```

```
*RUDDER AND SPEEDBRAKE MIXER
          RUD=DELTR/GMR
          SB=DELTSB/GMS
          LPX=RUD+SB
*550-----------------------------------------------------------550
          RPX=RUD-SB
           LPMIX=HSTRSS(IC,-HMR,HMR,LPX)
          RPMIX=HSTRSS(IC,-HMSB,HMSB,RPX)
          RPHIN=RPMIX/GH
          LPHIN= LPMIX/GH
          LPHHS=HSTRSS(IC,-HH,HH,LPHIN)
          RPHHS=HSTRSS(IC,-HH,HH,RPHIN)
          LPHS=LPHHS-DLP
          RPHS=RPHHS-DRP
          TLP=LPHS*KHC
          TRP=RPHS*KHC
          HMLP = AFGEN(HINGE,DSBRHL)
          HMRP = -AFGEN(HINGE,DSBRHL)
          HLP = HMLP + AFGEN(HINGE,DRRHL)*0.5*SIGN(1.0,DRRHL)
          HRP = HMRP + AFGEN(HINGE,DRRHL)*0.5*SIGN(1.0,DRRHL)
          LDL=(TLP+HLP-LTPC-LBP)/JP
          RDL=(TRP+HRP-RTPC-RBP)/JP
          DDLP=INTGRL(IC,LDL)
          DDRP=INTGRL(IC,RDL)
*LEFT     PANEL AND RIGHT PANEL DEFLECTION(IN RHL PLANE)
          DLP=INTGRL(IC,DDLP)
          DRP=INTGRL(IC,DDRP)
          LTPC=FCNSW(DDLP,-TPC,0.0,TPC)
          RTPC=FCNSW(DDRP,-TPC,0.0,TPC)
          LBP=DDLP*BPP
          RBP=DDRP*BPP
          LPDEG=DLP*RAD
          RPDEG=DRP*RAD
          DRRHL=(LPDEG+RPDEG)/2.
          DSBRHL=LPDEG-RPDEG
*CHANGING DEFLECTION TO FRL PLANE
          DRFRL=DRRHL*KR
          DSBFRL=DSBRHL*KSB
*         LPACC= LEFT PANEL ACCELERATION (RHL IN DEG/SEC**2)
          LPACC = INTGRL (IC,LPDEG)
*         RPACC= RIGHT PANEL ACCELERATION (RHL IN DEG/SEC**2)
          RPACC = INTGRL(IC,RPDEG)
*         DSBACC= SPEEDBRAKE SEPARATION ANGLE ACCELERATION (RHL DEG/SEC**2)
          DSBACC = INTGRL(IC,DSBRHL)
TERMINAL
METHOD RKSFX
TIMER DELT=0.00005,OUTDEL=0.010,FINTIM=2.0
LABEL RUDDER RUN 10 DEG/SEC COMMAND                          TP 6.20.75
OUTPUT   RINI,QL1GPM,QL2GPM,QL3GPM
          OUTPUT RINI,RM1RPM,RM2RPM,RM3RPM
          OUTPUT LPACC,RPACC,DSBACC
OUTPUT RINI,RPDEG
OUTPUT RINI,LPDEG
END
STOP
```

```
CUTPUT VARIABLE SEQUENCE
RIN1    RVIN1   RVZ1    RASAI1  RIL1    RT1     RTIN1   G2      RFP1    XRL
RFT1    RFX1    RFXLM1  RXSS1   RF1FLW  G1      DR1X1   R1X1    RXA1    RSAP1
RF1FT   RDDSP1  RDSP1   RSP1    RPVS1   R100    RQXSA1  RDXSA1  RXSA1   RIN2
RVIN2   RVZ2    RASAI2  RIL2    RT2     RTIN2   RFP2    RFT2    RFX2    RFXLM2
RXSS2   RF2FLW  DR2X1   R2X1    RXA2    RSAP2   RF2FT   RDDSP2  RDSP2   RSP2
RPVS2   R200    RQXSA2  RDXSA2  RXSA2   RIN3    RVIN3   RVZ3    RASAI3  RIL3
RT3     RTIN3   RFP3    RFT3    RFX3    RFXLM3  RXSS3   RF3FLW  DR3X1   R3X1
RXA3    RSAP3   RF3FT   RDDSP3  RDSP3   RSP3    RPVS3   R300    RQXSA3  RDXSA3
RXSA3   RIN4    RVIN4   RVZ4    RASAI4  RIL4    RT4     RTIN4   RFP4    RFT4
RFX4    RFXLM4  RXSS4   RF4FLW  DR4X1   R4X1    RXA4    RSAP4   RF4FT   RDDSP4
RDSP4   RSP4    RPVS4   R400    RQXSA4  RDXSA4  RXSA4   RF1     RF2     RF3
RF4     FRTOT   RX3     PL3     PL3LIM  PV3     RBF3    RX2     PL2     PL2LIM
PV2     RBF2    RX1     PL1     PL1LIM  PV1     RBF1    RBF     Y1      XRDOT
RSVFF   FR      XRDFB   Y2      XRDDOT  XRD     XR      QL3     RSVMI3  RSVI3
QL2     RSVMI2  RSVI2   QL1     RSVMI1  RSVI1   RMIN3   RTSW3   DELTR3  DELTR2
DELTR1  RUDSUM  DELTR   RUD     DELTS3  DELTS2  DELTS1  SBSUM   DELTSB  SB
LPX     LPMIX   LPHIN   LPHHS   LPHS    TLP     RPX     RPMIX   RPHIN   RPHHS
RPHS    TRP     RTF3    RMSUM1  RMSUM2  THD3    THDOT3  RTHET3  RMIN2   RTSW2
RTF2    RMSUM3  RMSUM4  THD2    THDOT2  RTHET2  RMIN1   RTSW1   RTF1    RMSUM5
RMSUM6  THD1    THDOT1  RTHET1  DRVL1   RVL1    RVW1    RDDVW1  RDVW1   ZZ1035
RDVK1   RDVKI1  RVK1    RUDFB   RLV1    RLVDT1  RDDVZ1  RDVZ1   ZZ1039  DRVL2
RVL2    RVW2    RDDVW2  RDVW2   ZZ1042  RDVK2   RDVKI2  RVK2    RLV2    RLVDT2
RDDVZ2  RDVZ2   ZZ1046  DRVL3   RVL3    RVW3    RDDVW3  RDVW3   ZZ1049  RDVK3
RDVKI3  RVK3    RLV3    RLVDT3  RDDVZ3  RDVZ3   ZZ1053  DRVL4   RVL4    RVW4
RDDVW4  RDVW4   ZZ1056  RDVK4   RDVKI4  RVK4    RLV4    RLVDT4  RDDVZ4  RDVZ4
ZZ1060  SIN1    SVIN1   SVZ1    SASAI1  SIL1    ST1     STIN1   SFP1    XSL
SFT1    SFX1    SFXLM1  SXSS1   SF1FLW  DS1X1   S1X1    SXA1    SSAP1   SF1FT
SDDSP1  SDSP1   SSP1    SPVS1   S100    SQXSA1  SDXSA1  SXSA1   SIN2    SVIN2
SVZ2    SASAI2  SIL2    ST2     STIN2   SFP2    SFT2    SFX2    SFXLM2  SXSS2
SF2FLW  DS2X1   S2X1    SXA2    SSAP2   SF2FT   SDDSP2  SDSP2   SSP2    SPVS2
S200    SQXSA2  SDXSA2  SXSA2   SIN3    SVIN3   SVZ3    SASAI3  SIL3    ST3
STIN3   SFP3    SFT3    SFX3    SFXLM3  SXSS3   SF3FLW  DS3X1   S3X1    SXA3
SSAP3   SF3FT   SDDSP3  SDSP3   SSP3    SPVS3   S300    SQXSA3  SDXSA3  SXSA3
SIN4    SVIN4   SVZ4    SASAI4  SIL4    ST4     STIN4   SFP4    SFT4    SFX4
SFXLM4  SXSS4   SF4FLW  DS4X1   S4X1    SXA4    SSAP4   SF4FT   SDDSP4  SDSP4
SSP4    SPVS4   S400    SQXSA4  SDXSA4  SXSA4   SF1     SF2     SF3     SF4
FSTOT   SX3     PSL3    PSL3LM  SPV3    SBF3    SX2     PSL2    PSL2LM  SPV2
SBF2    SX1     PSL1    PSL1LM  SPV1    SBF1    SBF     Z1      XSDOT   SSVFF
FS      XSDFB   Z2      XSDDOT  XSD     XS      QSL1    SSVMI1  SSVI1   QSL2
SSVMI2  SSVI2   QSL3    SSVMI3  SSVI3   SMIN3   STSW3   STF3    SMSUM1  SMSUM2
STHD3   THDTS3  STHET3  SMIN2   STSW2   STF2    SMSUM3  SMSUM4  STHD2   THDTS2
STHET2  SMIN1   STSW1   STF1    SMSUM5  SMSUM6  STHD1   THDTS1  STHET1  DSVL1
SVL1    SVW1    SDDVW1  SDVW1   ZZ1096  SDVK1   SDVKI1  SVK1    SBFB    SLV1
SLVDT1  SDDVZ1  SDVZ1   ZZ1100  DSVL2   SVL2    SVW2    SDDVW2  SDVW2   ZZ1103
SDVK2   SDVKI2  SVK2    SLV2    SLVDT2  SDDVZ2  SDVZ2   ZZ1107  DSVL3   SVL3
SVW3    SDDVW3  SDVW3   ZZ1110  SDVK3   SDVKI3  SVK3    SLV3    SLVDT3  SDDVZ3
SDVZ3   ZZ1114  DSVL4   SVL4    SVW4    SDDVW4  SDVW4   ZZ1117  SDVK4   SDVKI4
SVK4    SLV4    SLVDT4  SDDVZ4  SDVZ4   ZZ1121  LPDEG   RPDEG   DSBRHL  HMLP
DRRHL   HLP     LTPC    LBP     LDL     DDLP    HMRP    HRP     RTPC    RBP
RDL     DDRP    DLP     DRP     LPACC   RPACC   DSBACC  QL3GPM  QL2GPM  QL1GPM
RM1RPM  RM2RPM  RM3RPM  QSL3GM  QSL2GM  QSL1GM  SM1RPM  SM2RPM  SM3RPM  DRFRL
DSBFRL
```

$$$ TRANSLATION TABLE CONTENTS $$$	CURRENT	MAXIMUM
MACRO AND STATEMENT OUTPUTS	519	600
STATEMENT INPUT WORK AREA	1489	1900
INTEGRATORS+MEMORY BLOCK OUTPUTS	117 + 0	300
PARAMETERS+FUNCTION GENERATORS	94 + 1	400
STORAGE VARIABLES+INTEGRATOR ARRAYS	0 + 0/2	50
HISTORY AND MEMORY BLOCK NAMES	21	50
MACRO DEFINITIONS AND NESTED MACROS	8	50
MACRO STATEMENT STORAGE	33	125
LITERAL CONSTANT STORAGE	0	100
SORT SECTIONS	1	20
MAXIMUM STATEMENTS IN SECTION	585	600

APPENDIX B

STEP RESPONSE PLOTS

APPENDIX B FIGURES

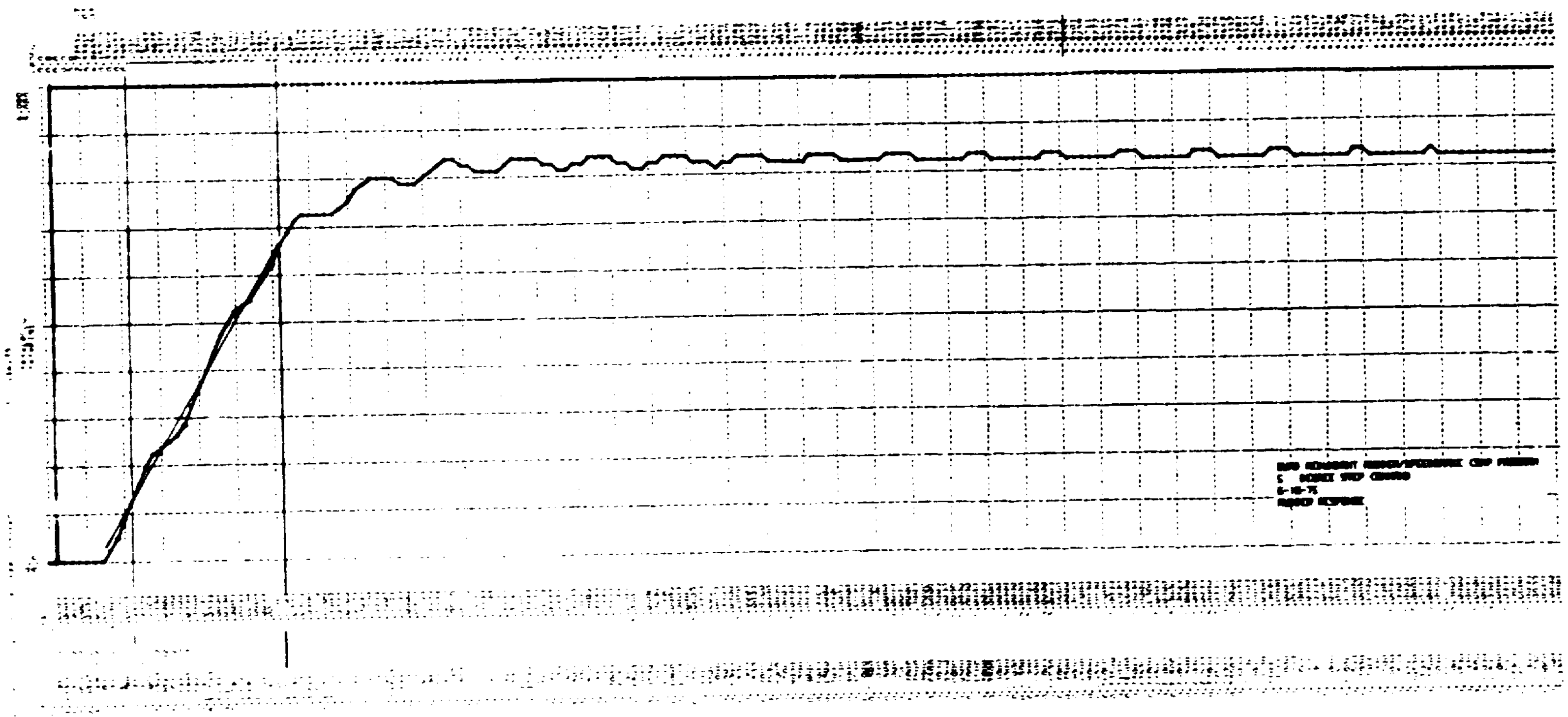


Figure B-1. — 5-degree Rudder step command response.

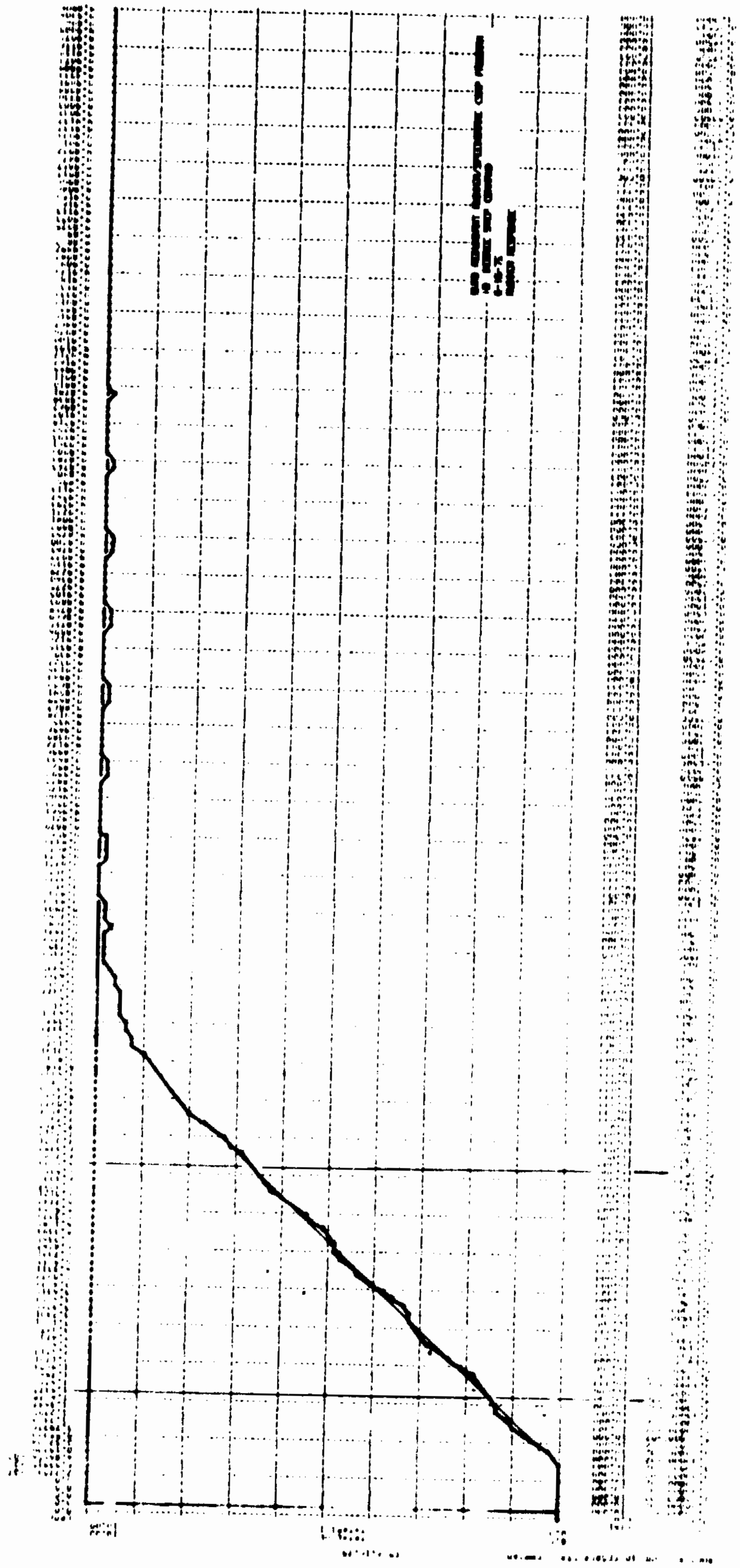


Figure B-2. - 10-degree Rudder step command response.

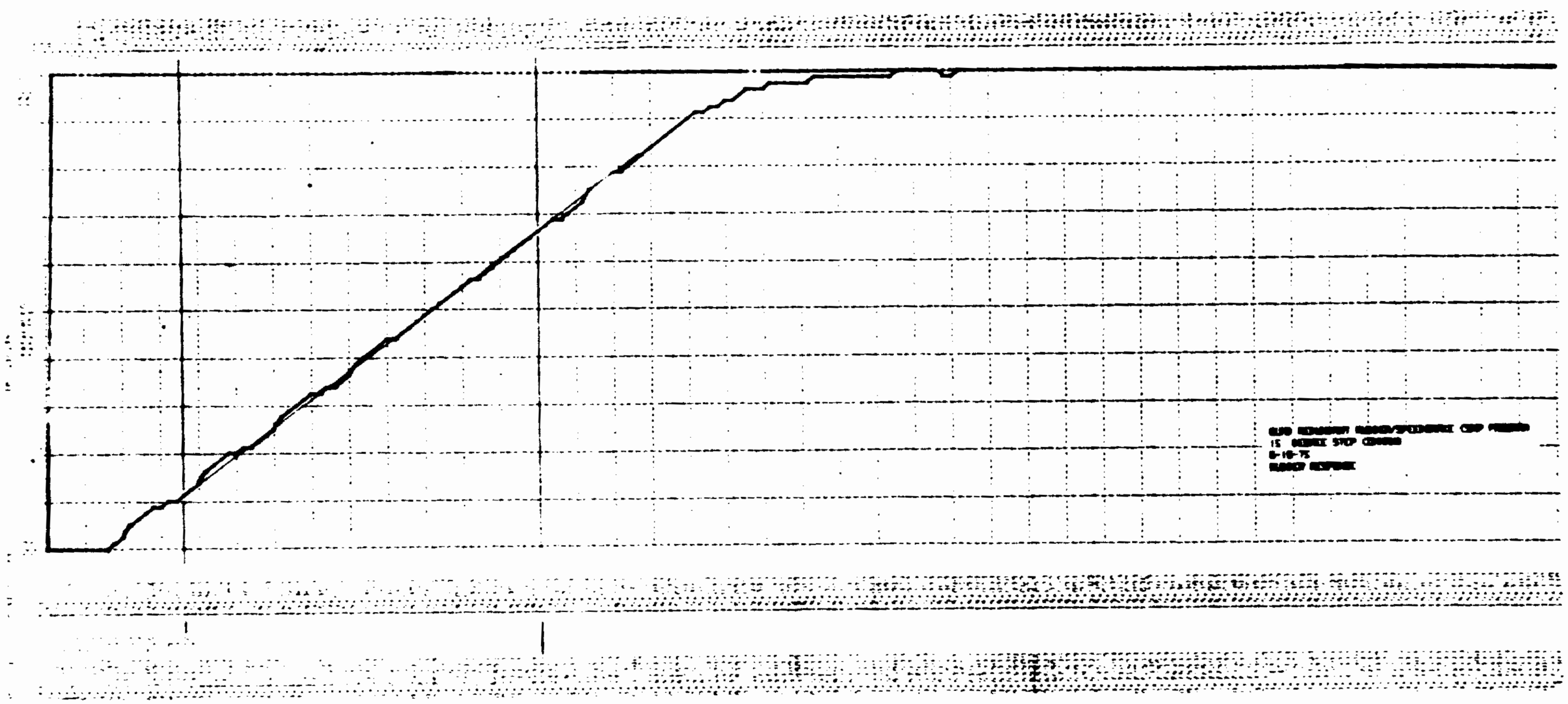


Figure B-3. — 15-degree Rudder step command response.

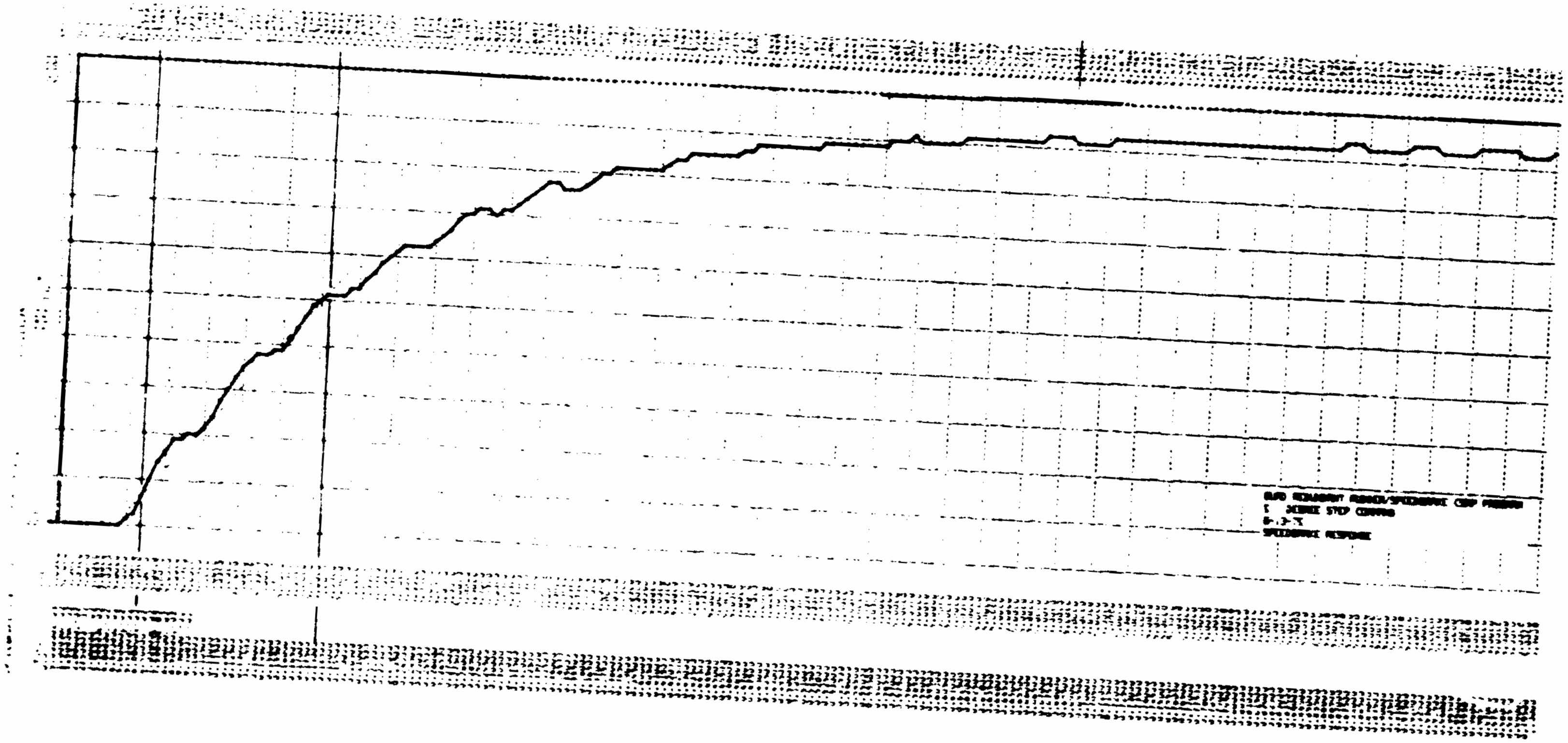


Figure B-4. – 5-degree Speedbrake step command response.

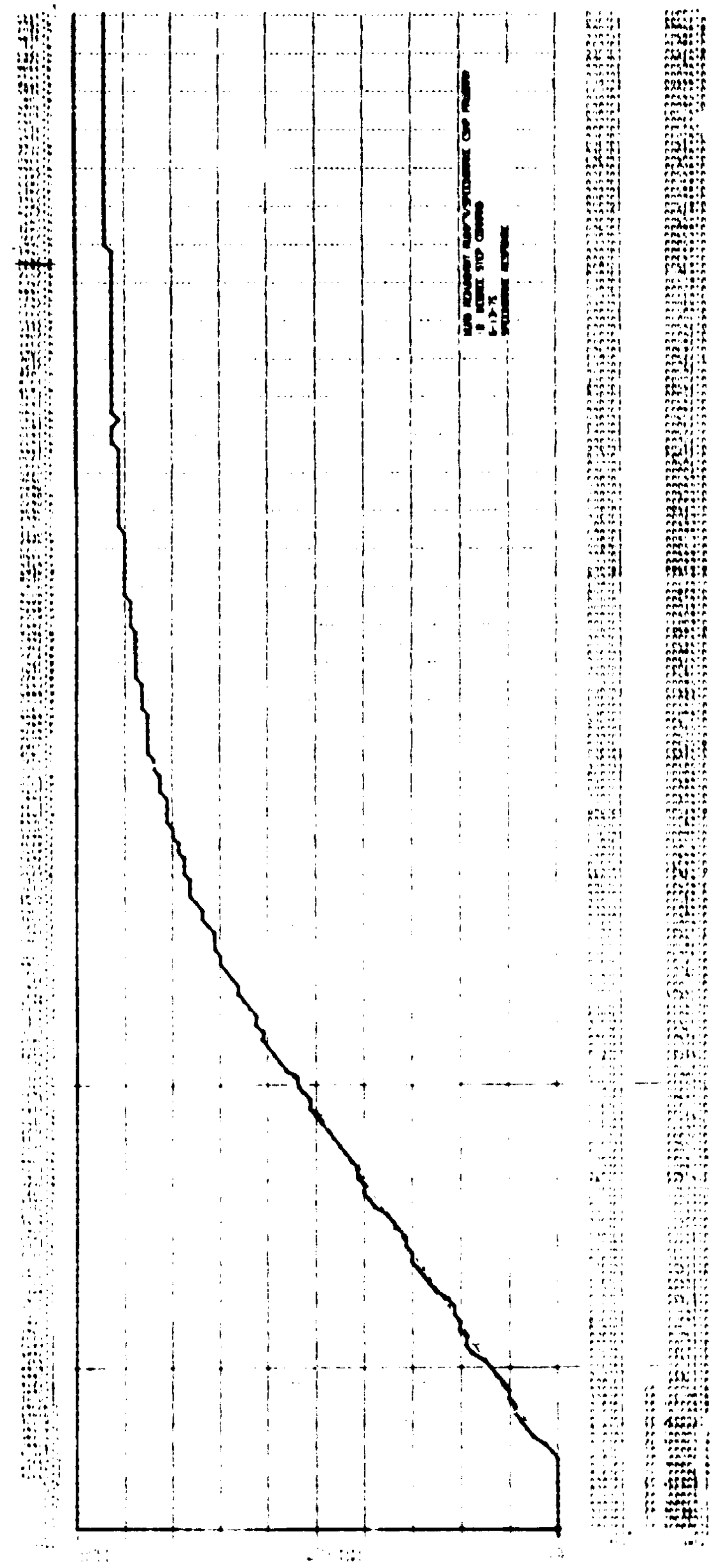


Figure B-5. — 10-degree Speedbrake step command response.

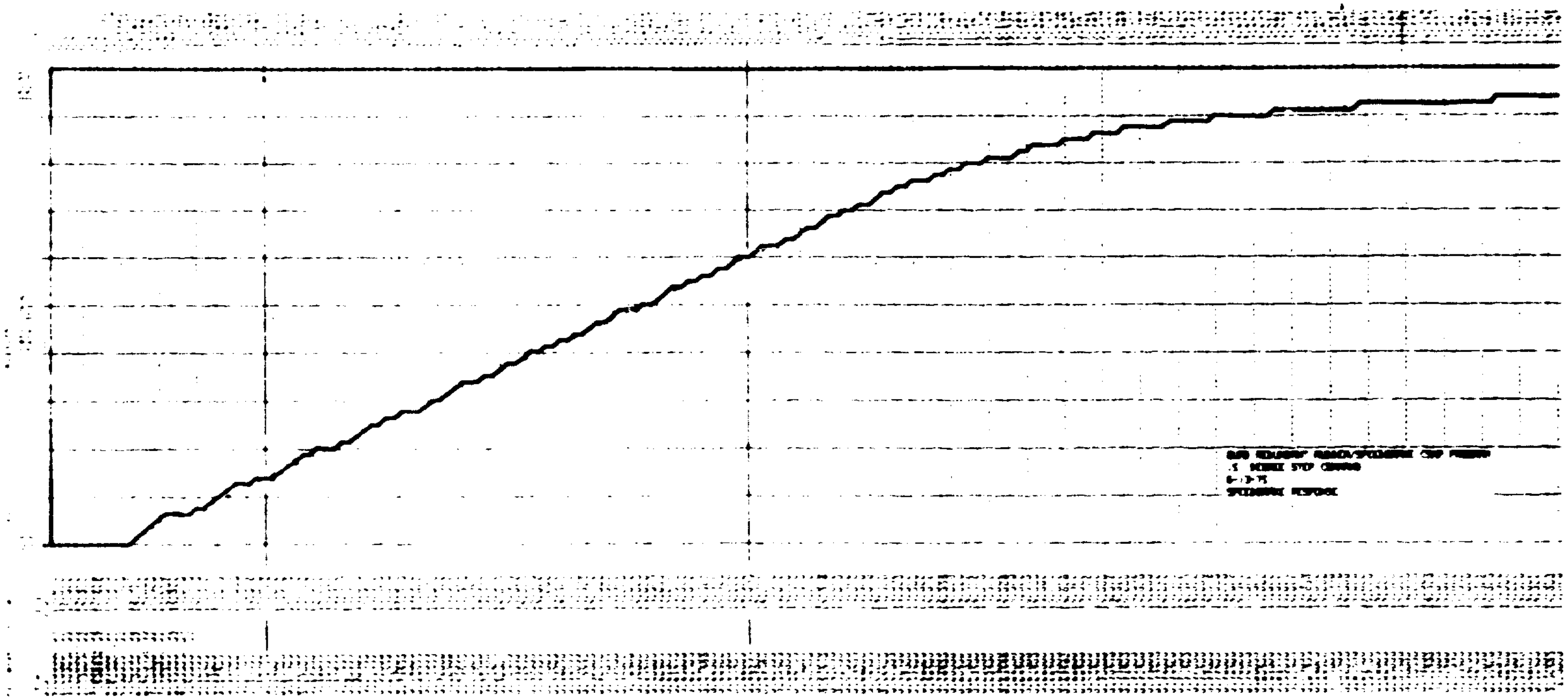


Figure B-6. – 15-degree Speedbrake step command response.

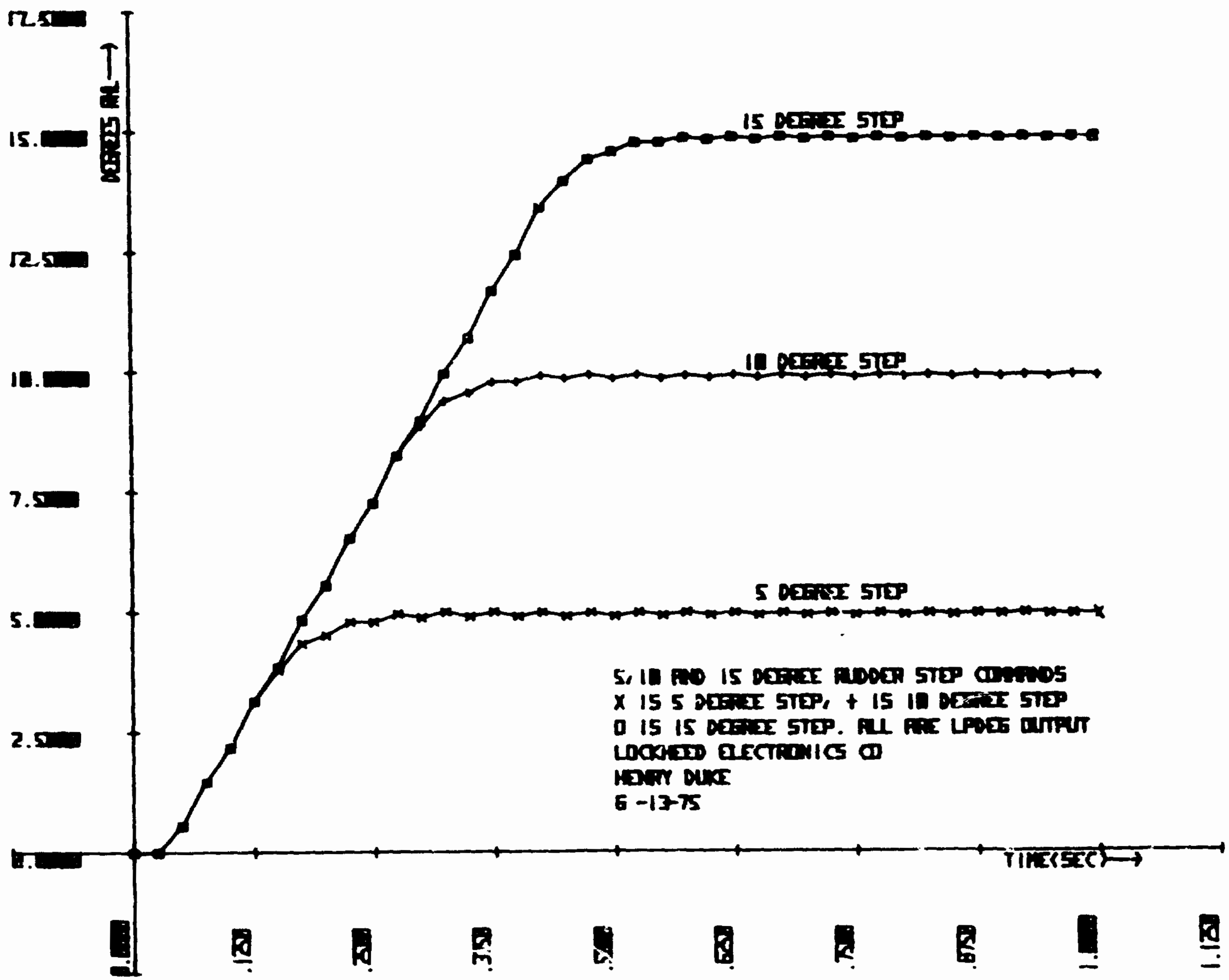


Figure B-7. - Various Rudder step commands.

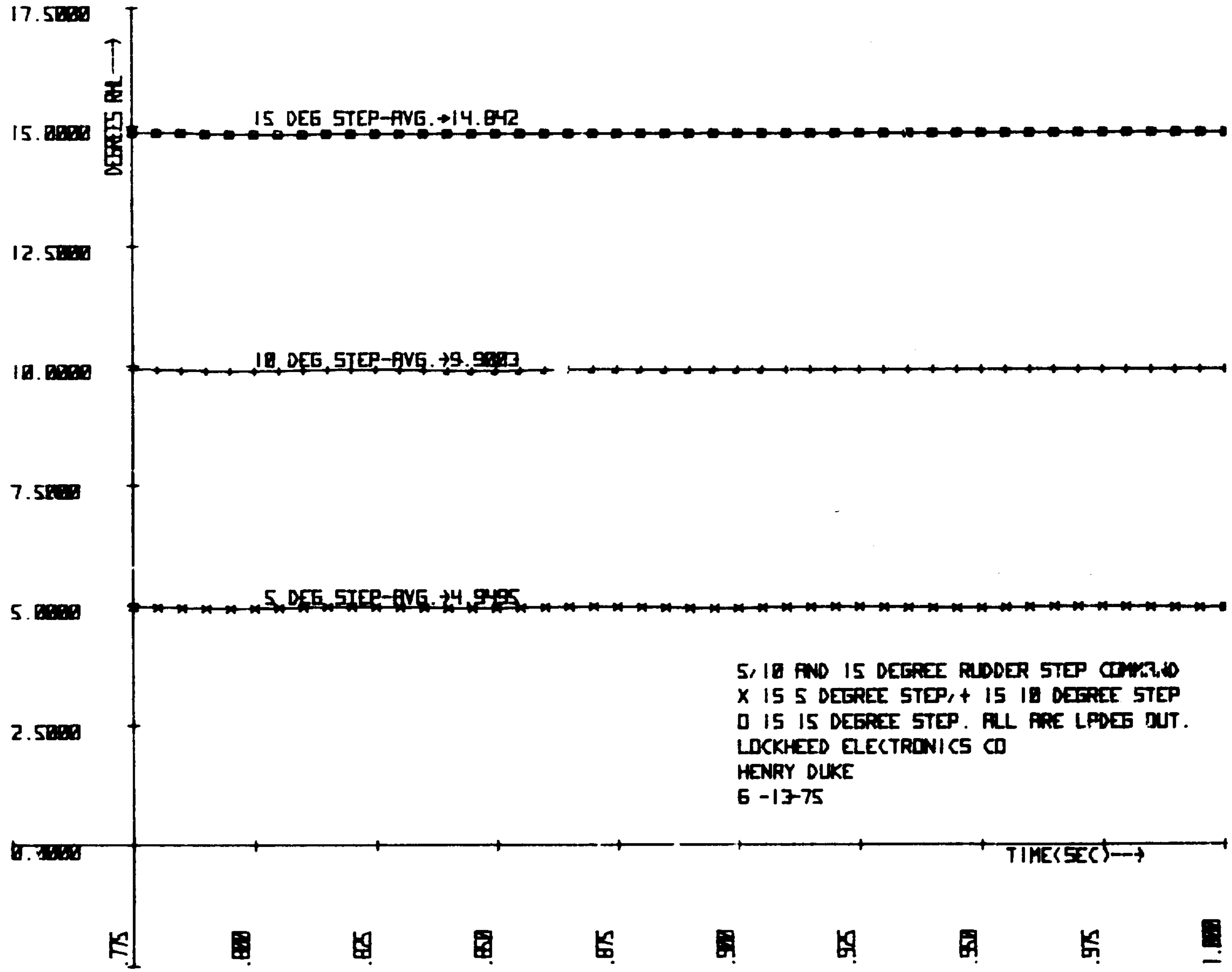


Figure B-8. – Various Rudder step commands.

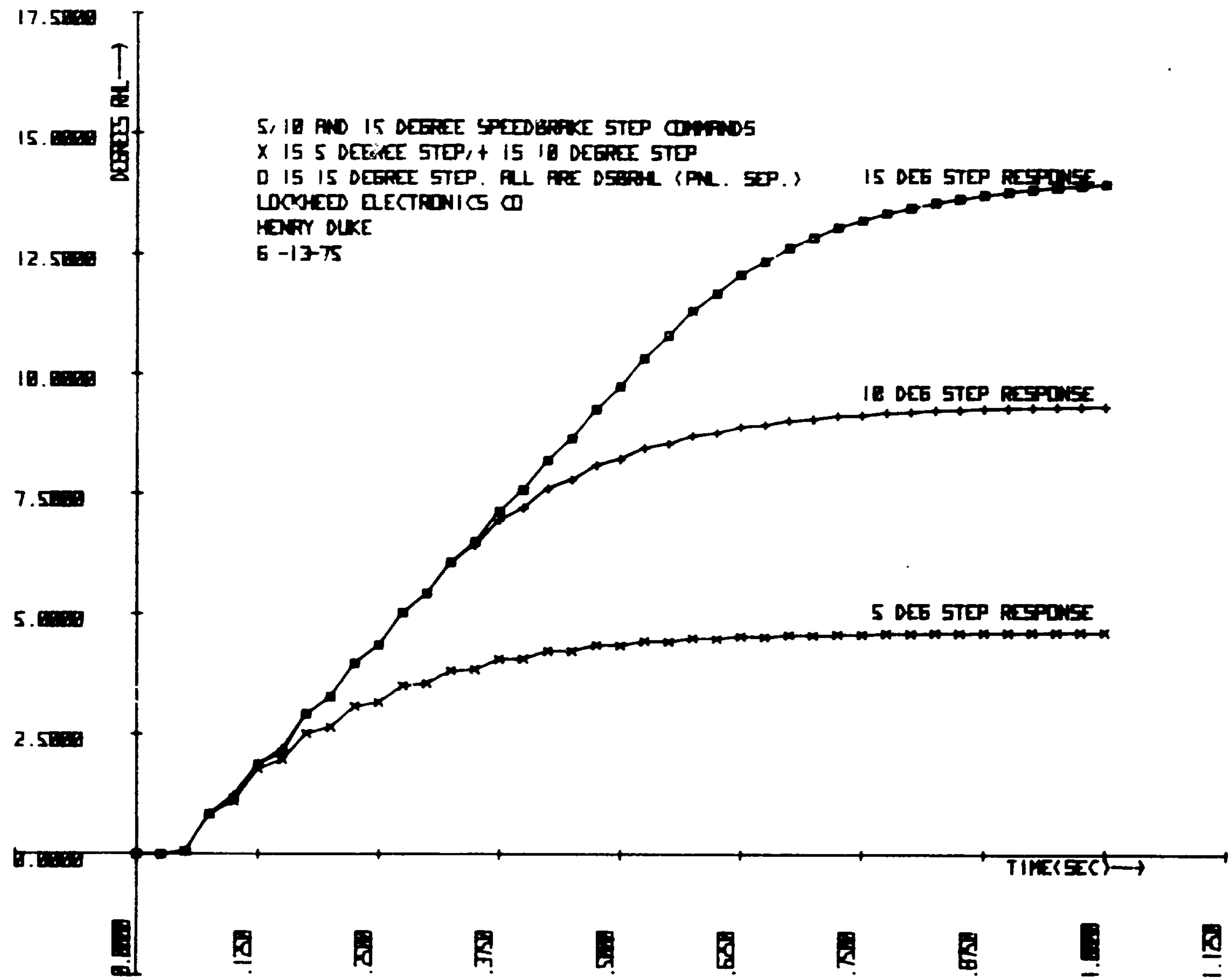


Figure B-9. - Various Speedbrake step commands.

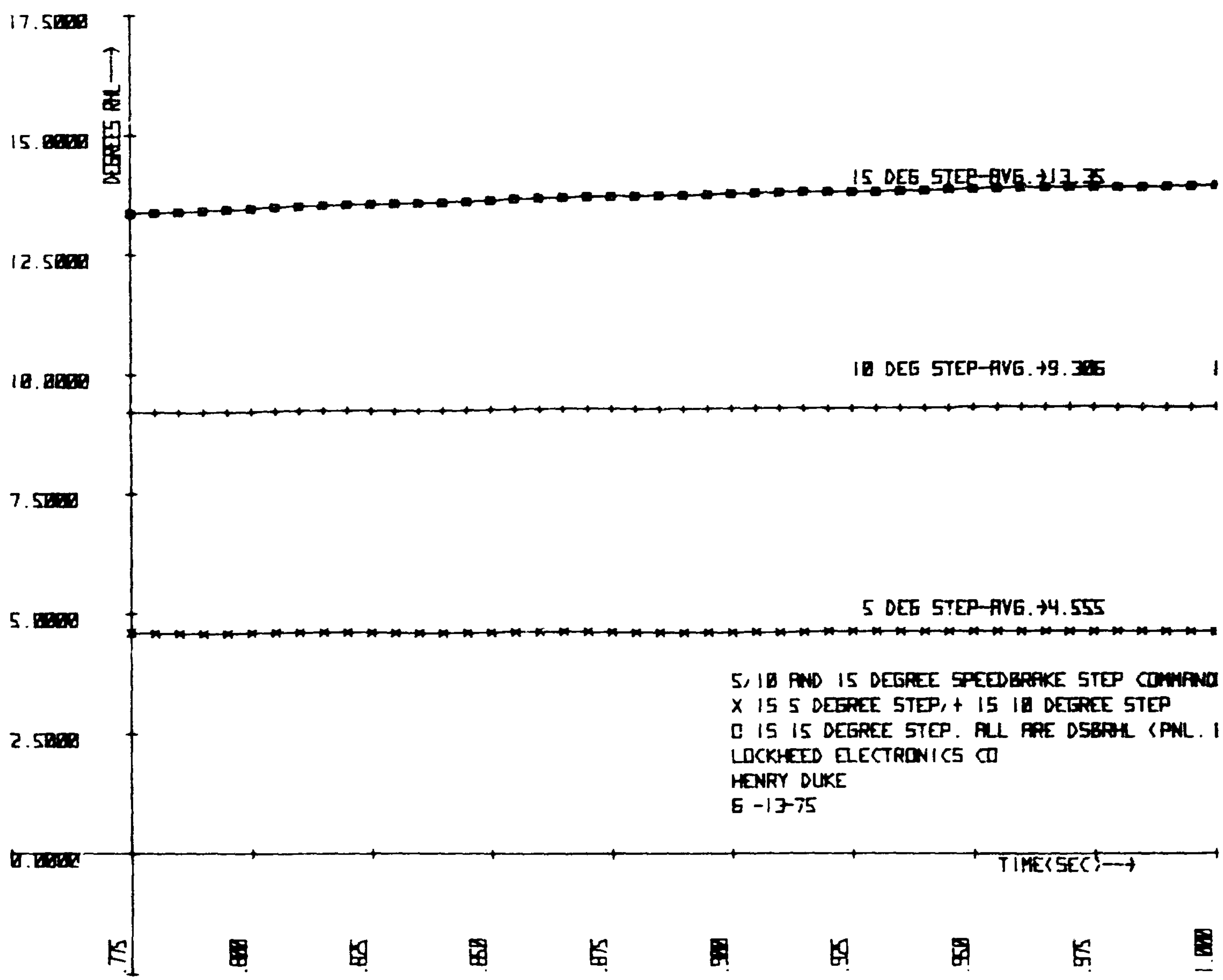


Figure B-10. - Various Speedbrake step commands.

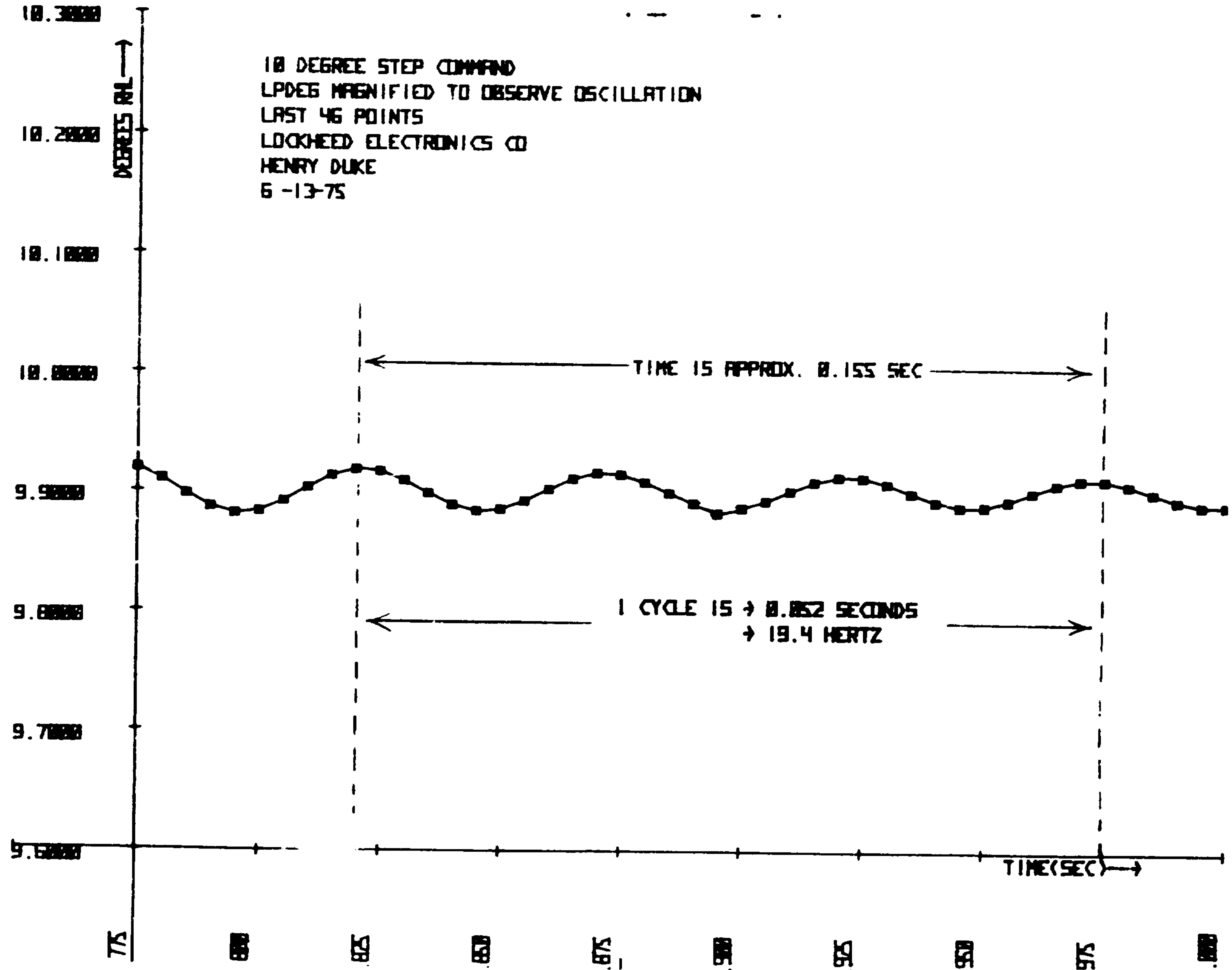


Figure B-11. – LPDEG magnified to observe oscillation.

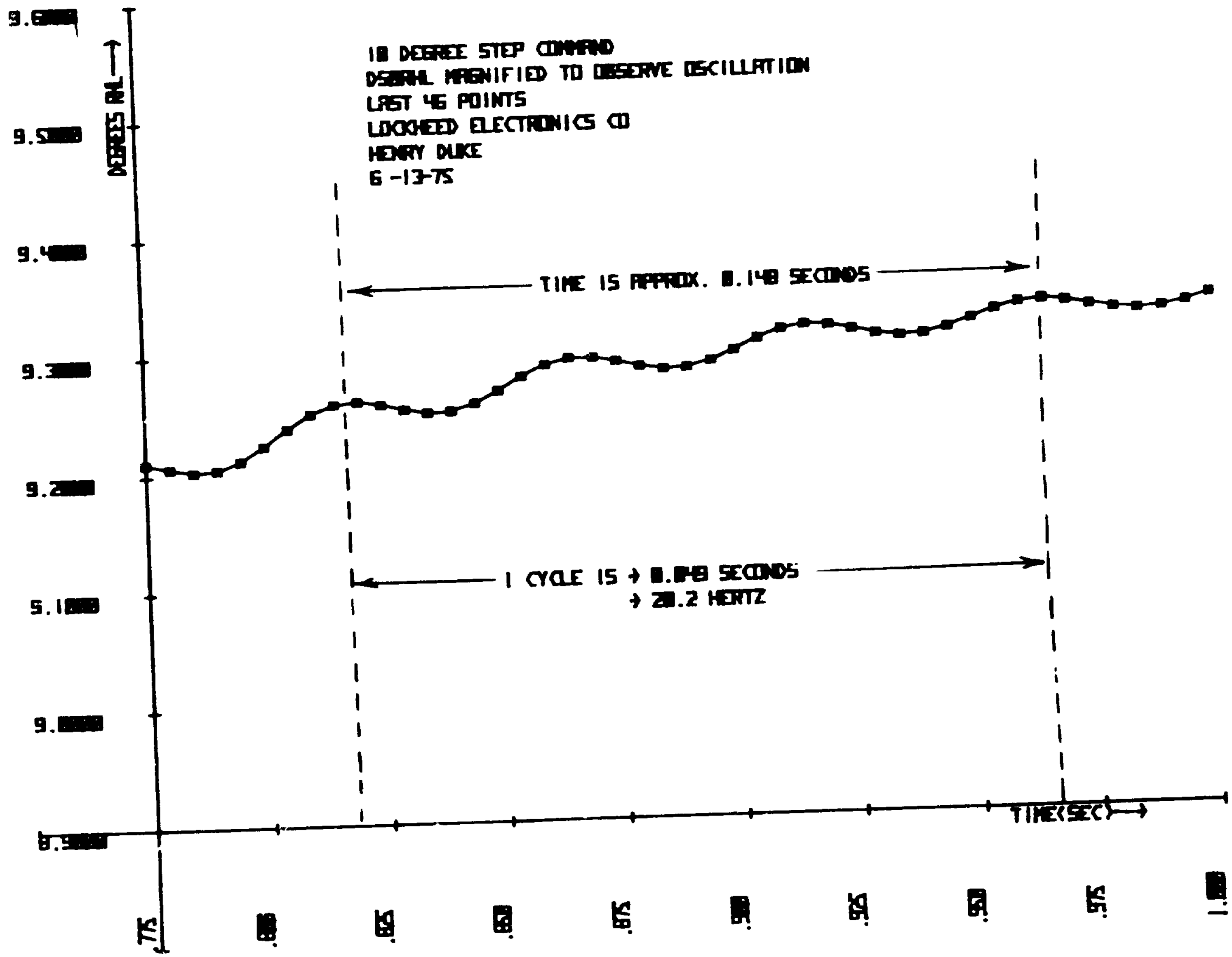


Figure B-12. – DSBRHL magnified to observe oscillation.

APPENDIX C

INITIAL STARTING POINTS
(RESPONSE DELAY)
TO A STEP COMMAND

APPENDIX C FIGURES

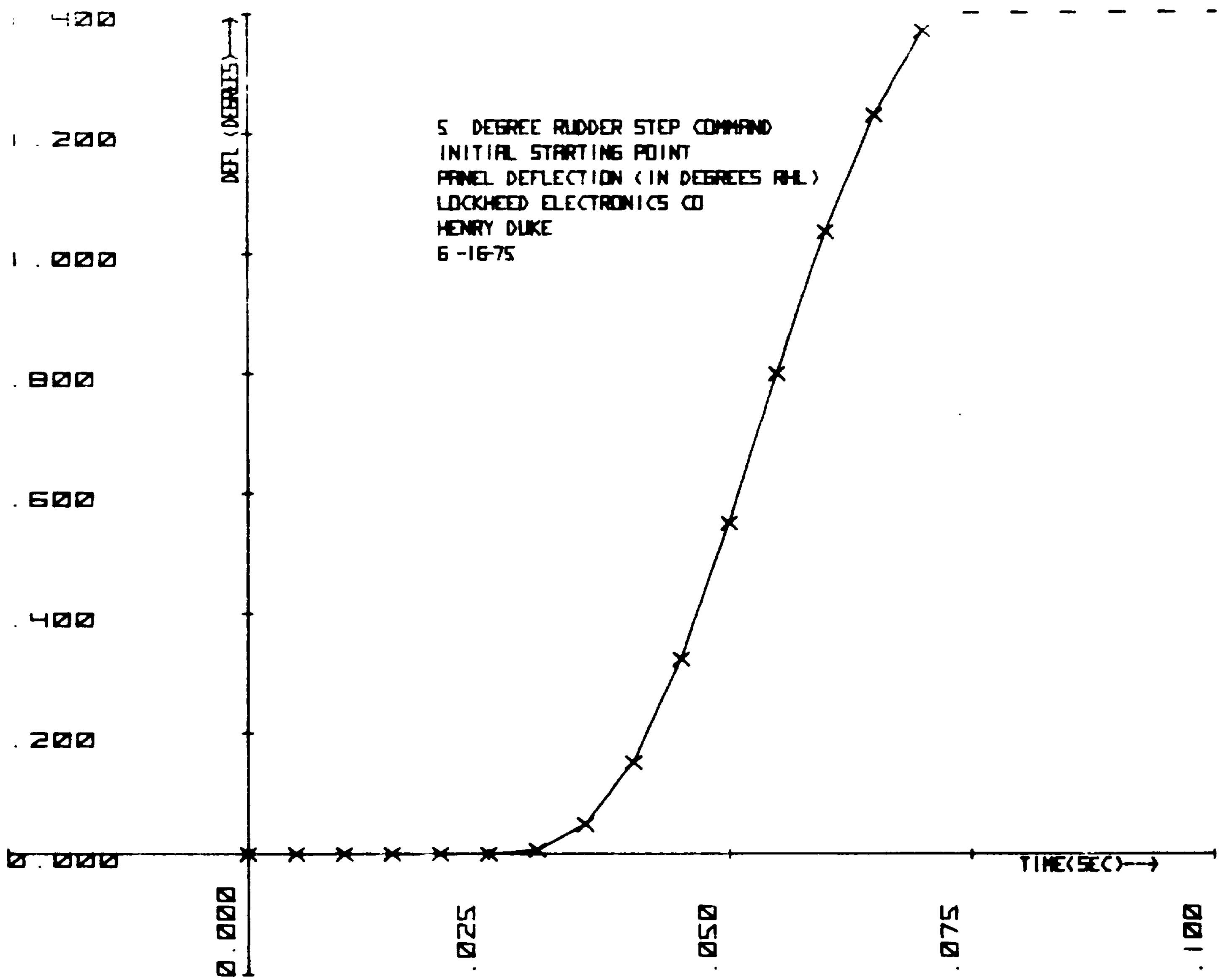


Figure C-1. – Initial starting point, 5-deg step.

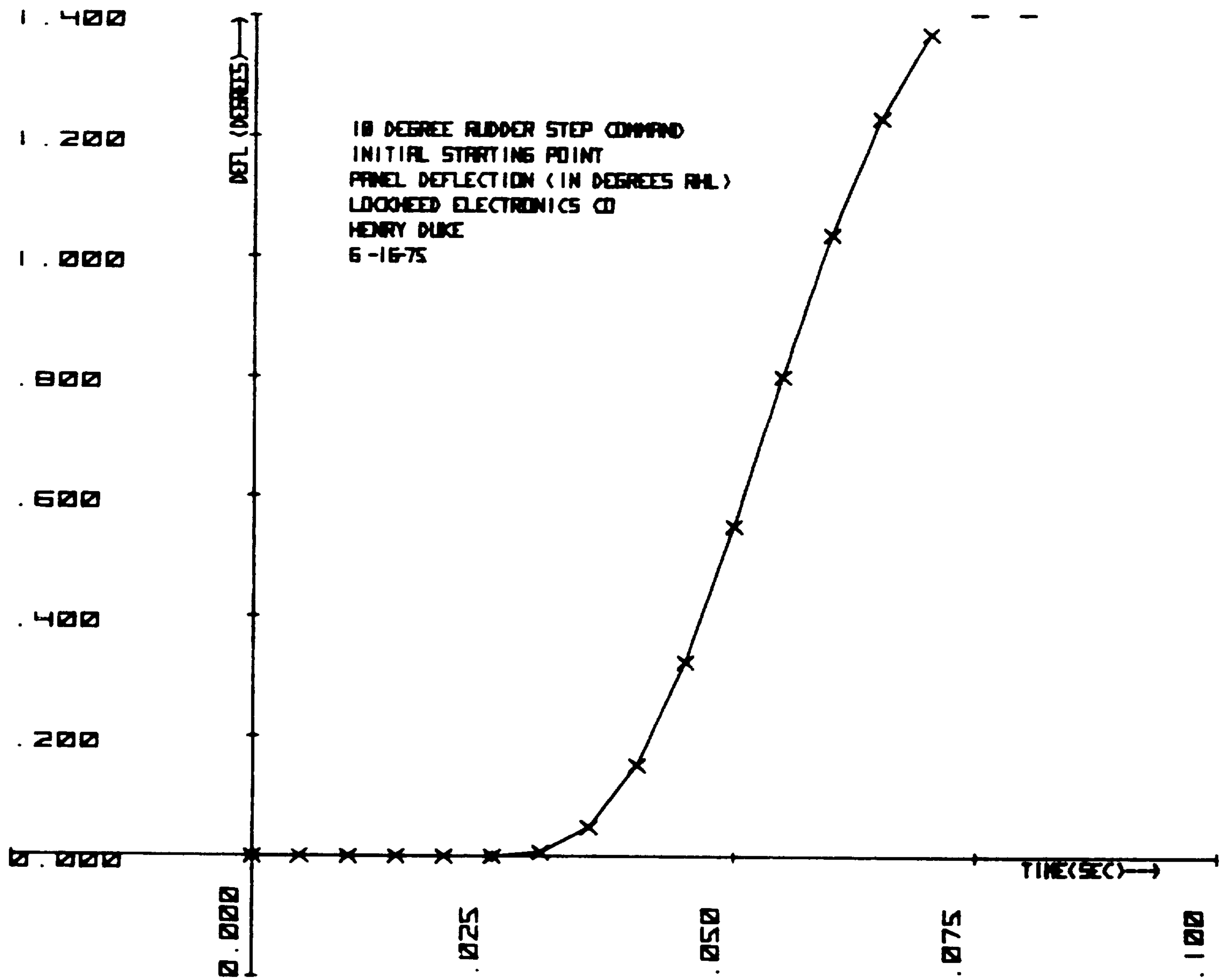


Figure C-2. – Initial starting point, 10-deg step.

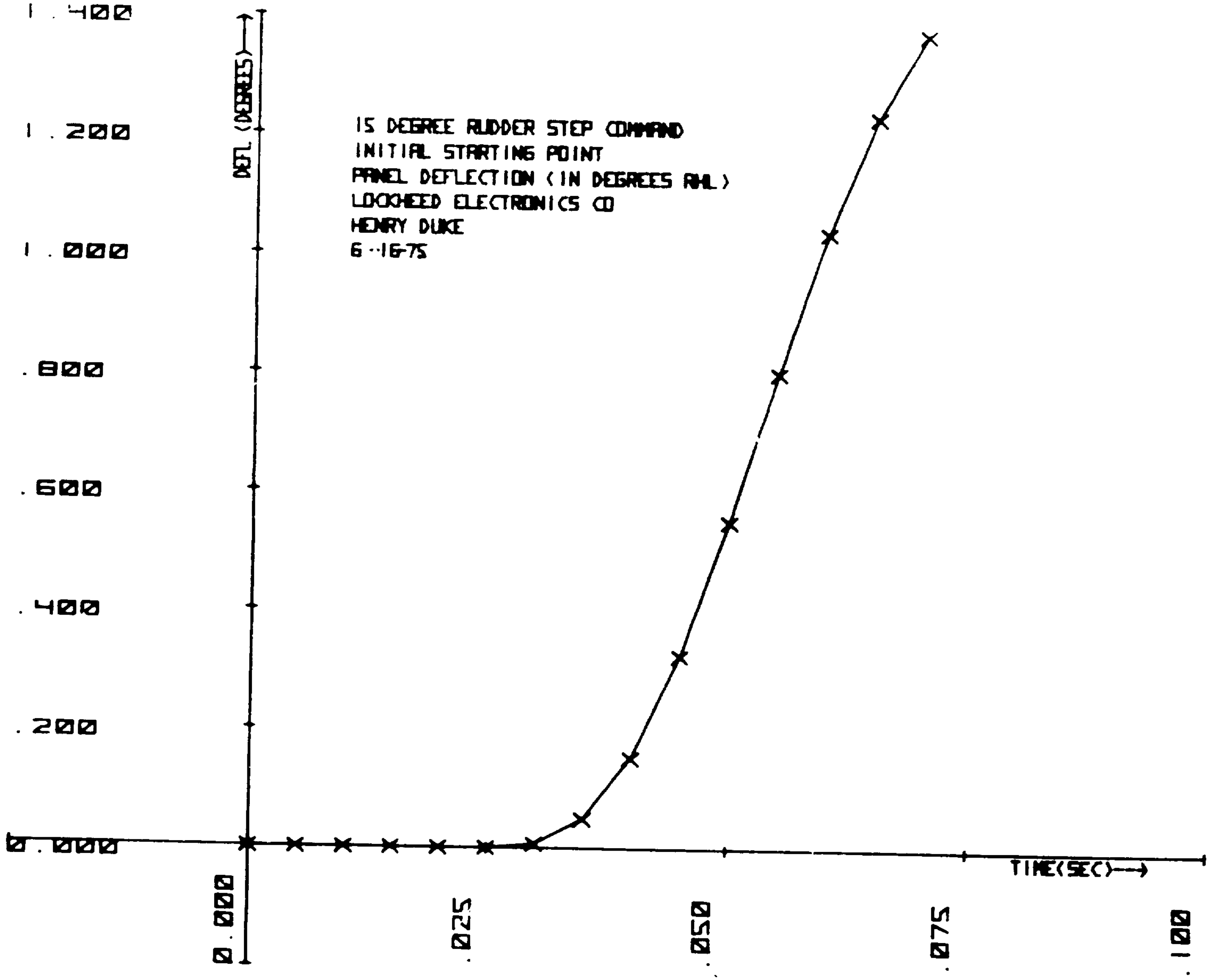


Figure C-3. – Initial starting point, 15-deg step.

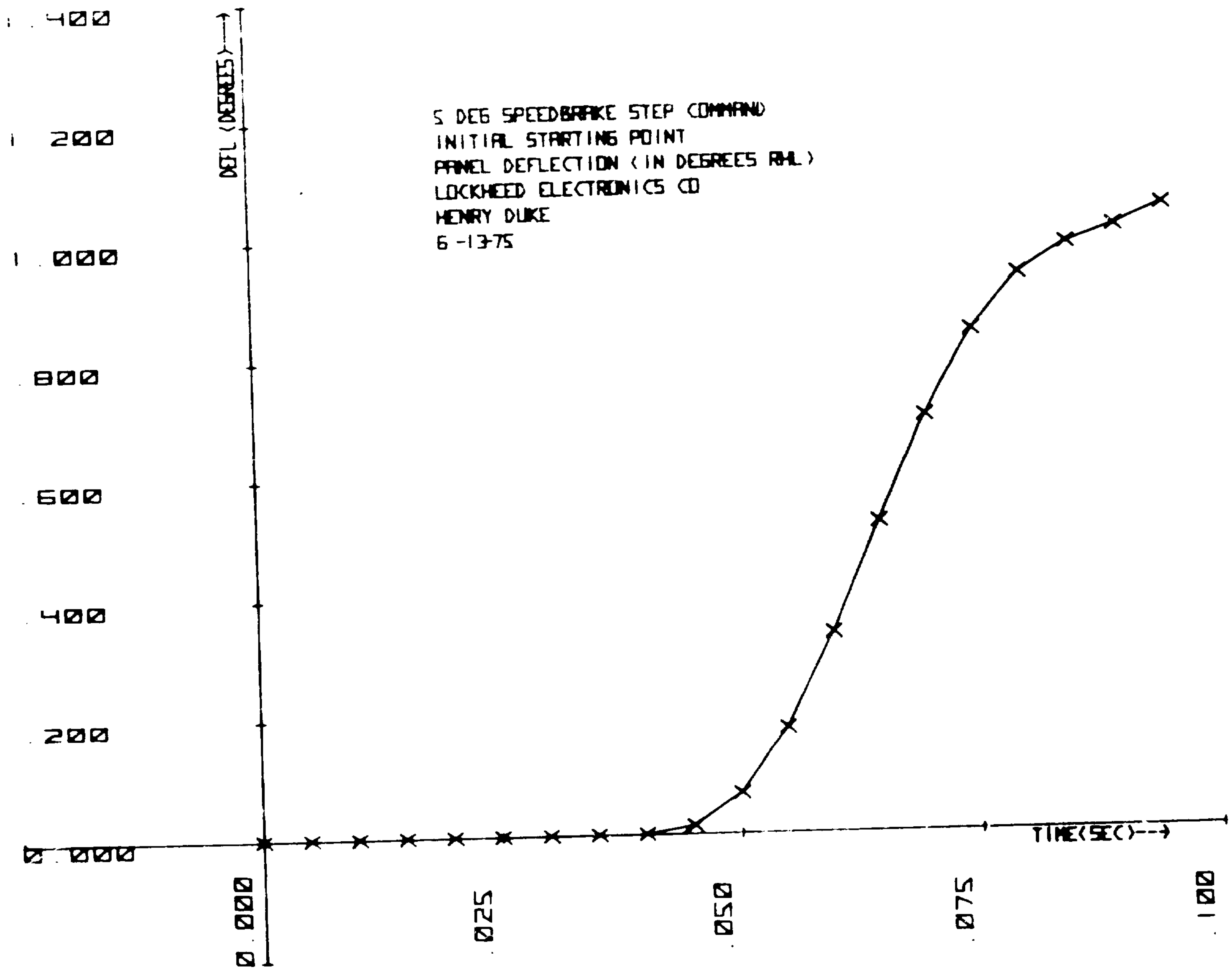


Figure C-4. – Initial starting point, 5-deg step.

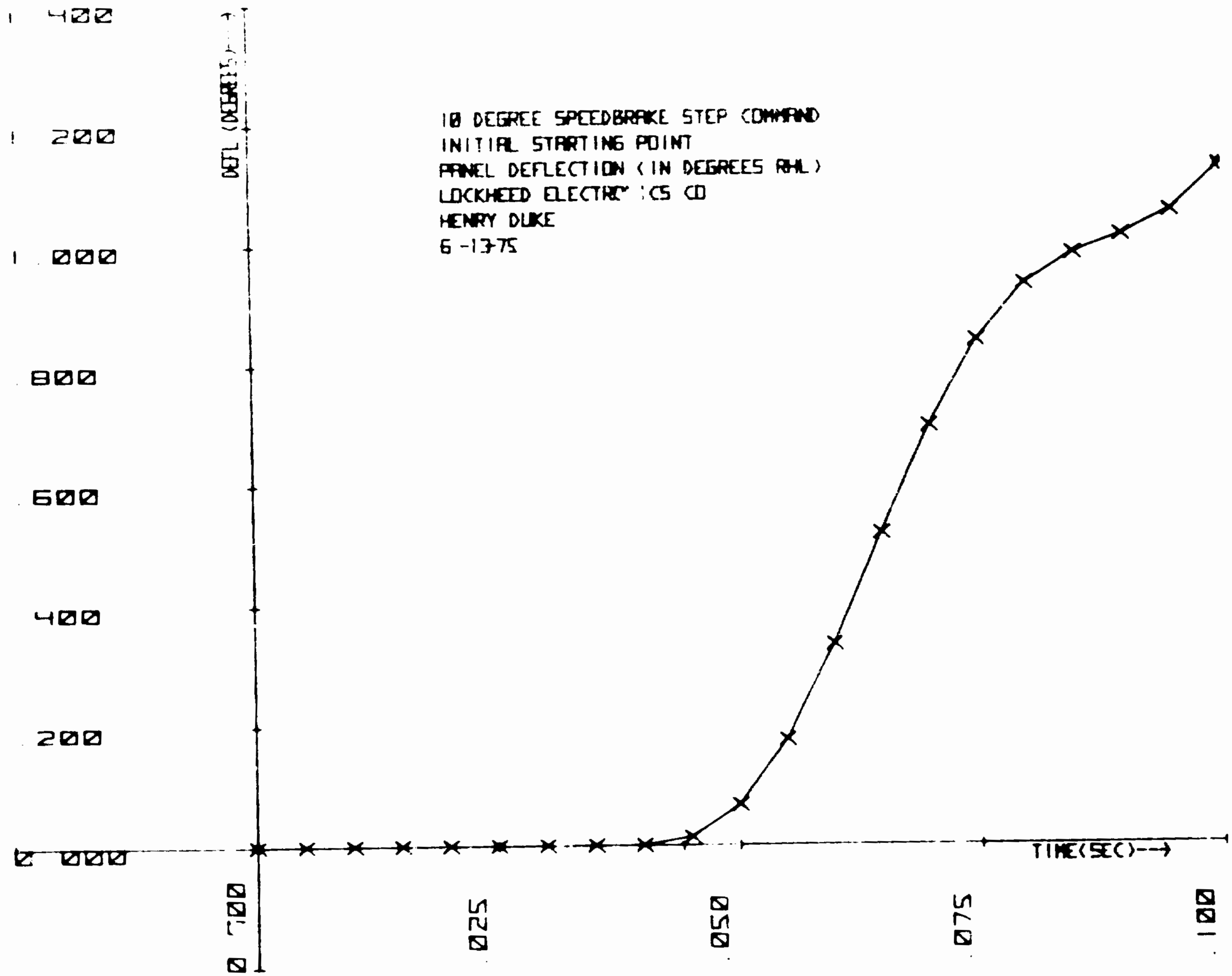


Figure C-5. – Initial starting point, 10-deg step.

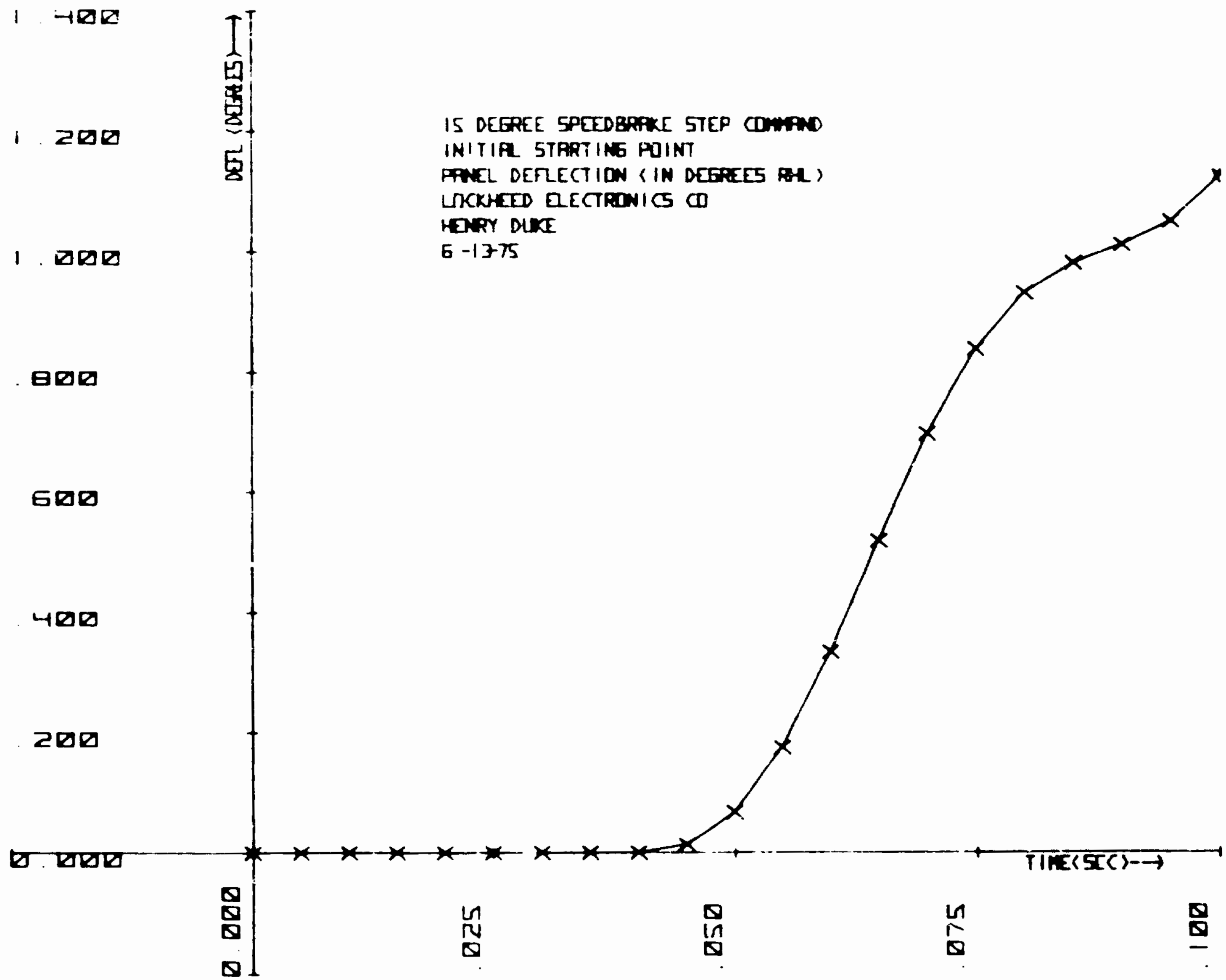


Figure C-6. – Initial starting point, 15-deg step.

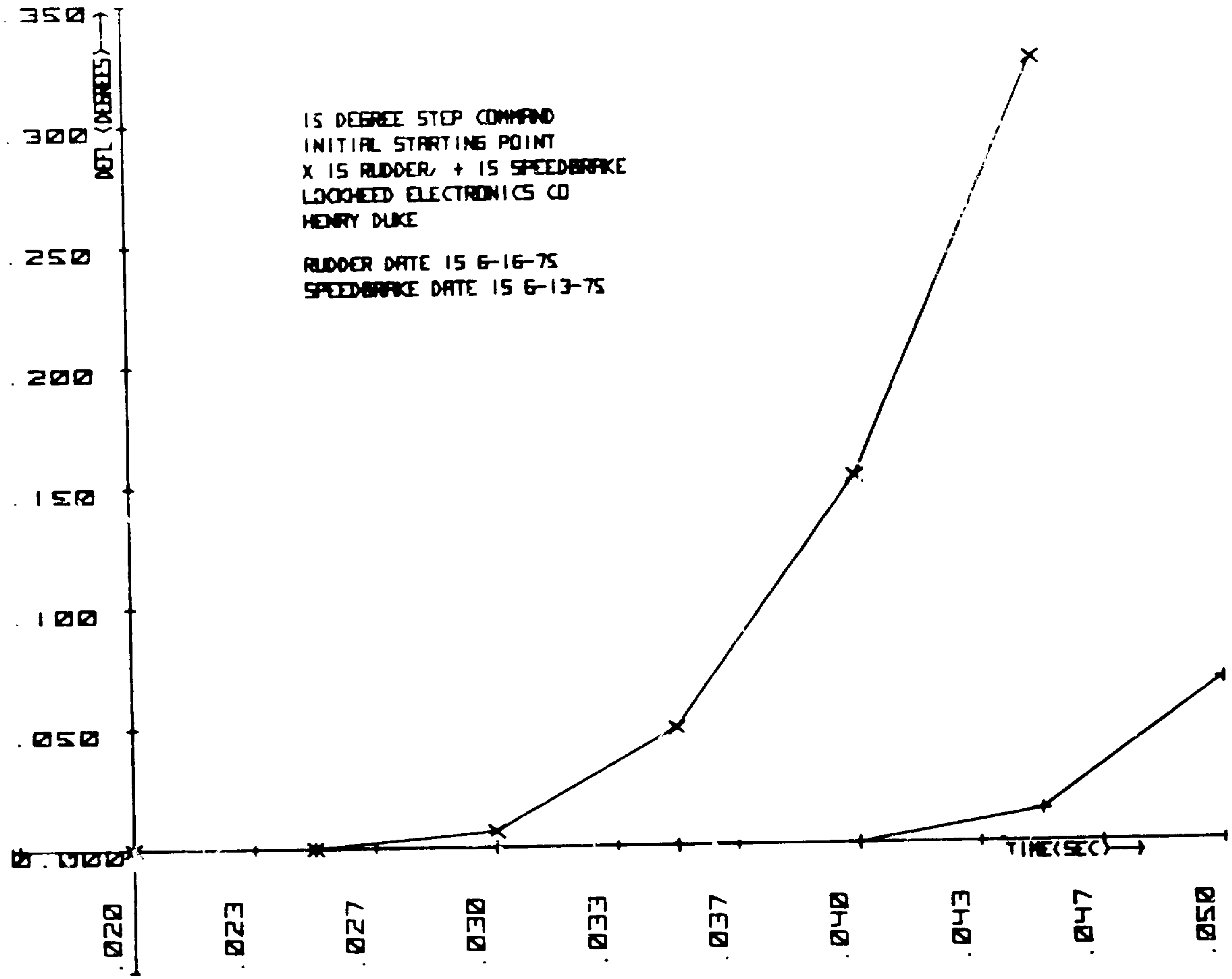


Figure C-7. - Initial starting point, 5-deg step.

APPENDIX D

RAMP RESPONSE CURVES

APPENDIX D FIGURES

Figure		Page

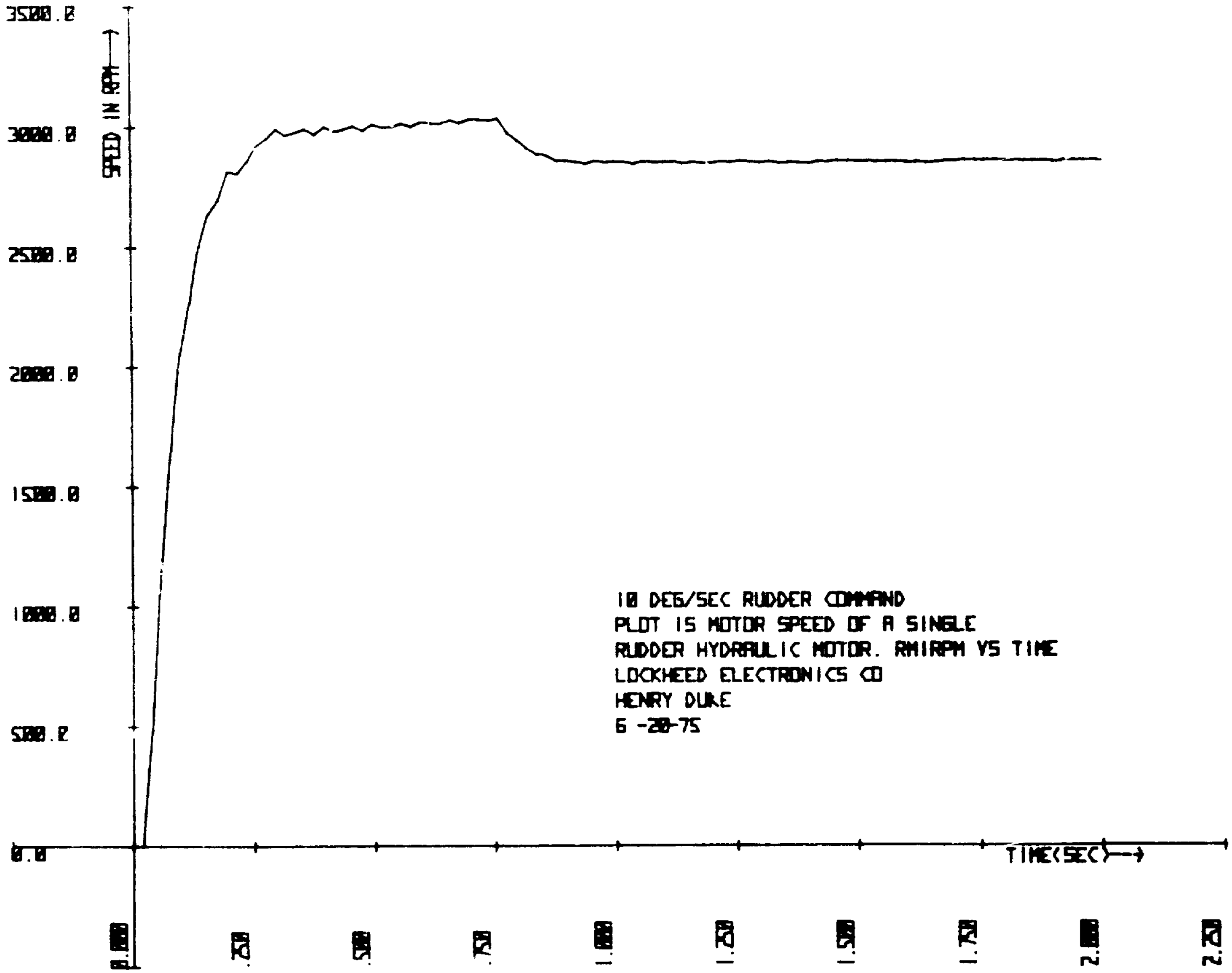


Figure D-1. — Motor speed of a single Rudder hydraulic motor for 10-deg/sec Rudder input.

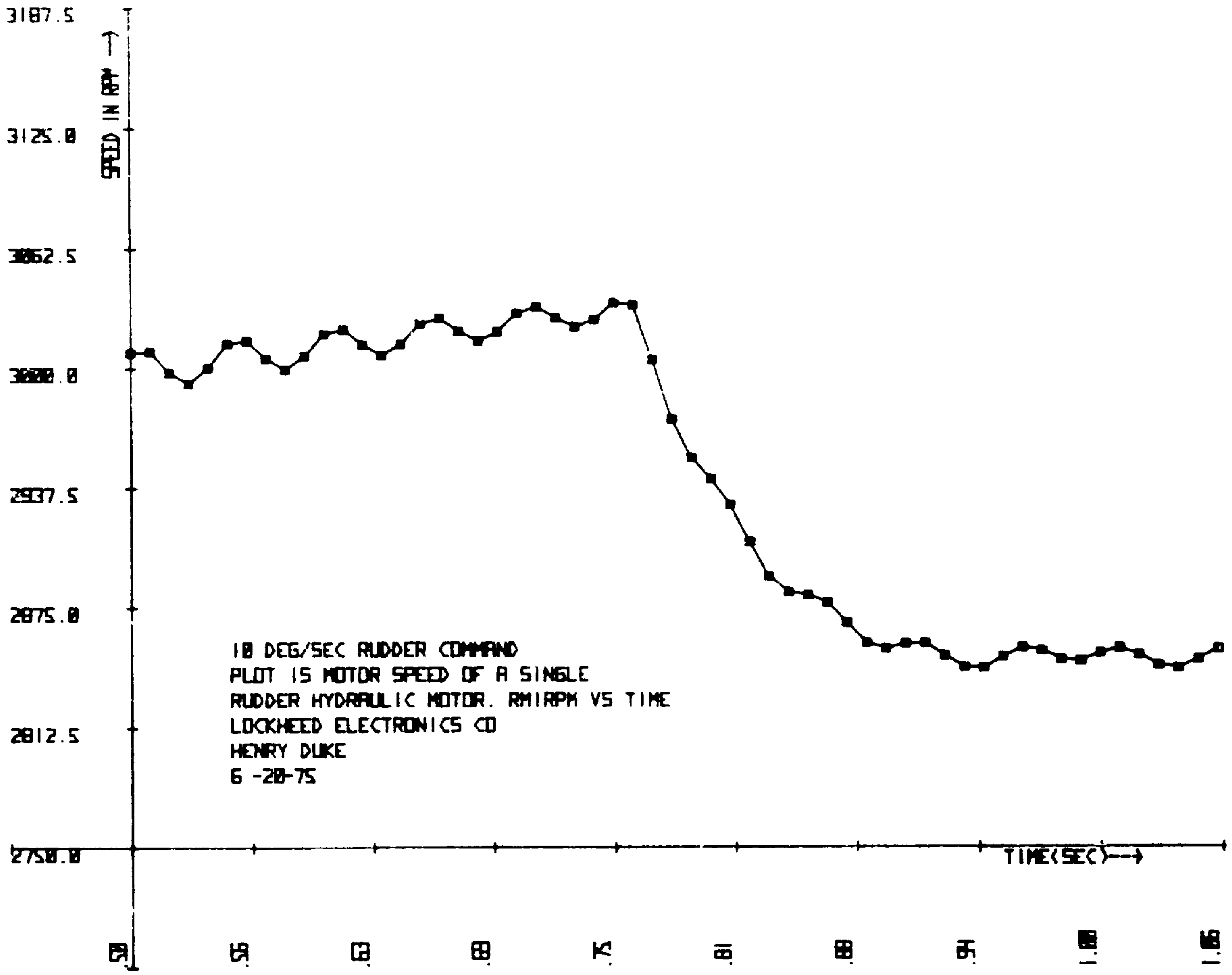


Figure D-2. -- Motor speed of a single Rudder hydraulic motor for 10-deg/'ec Rudder input.

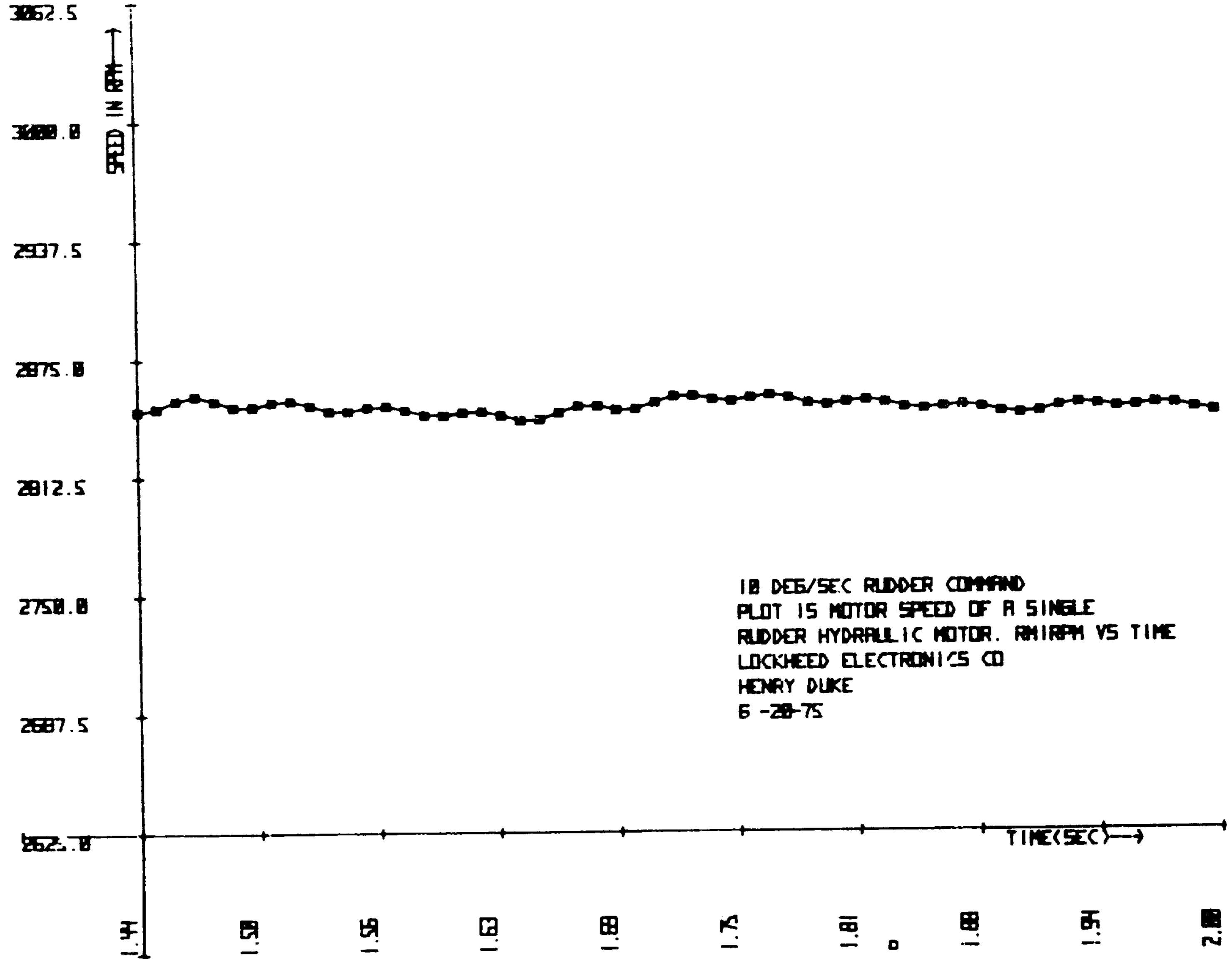


Figure D-3. – Motor speed of a single Rudder hydraulic motor for 10-deg/sec Rudder input.

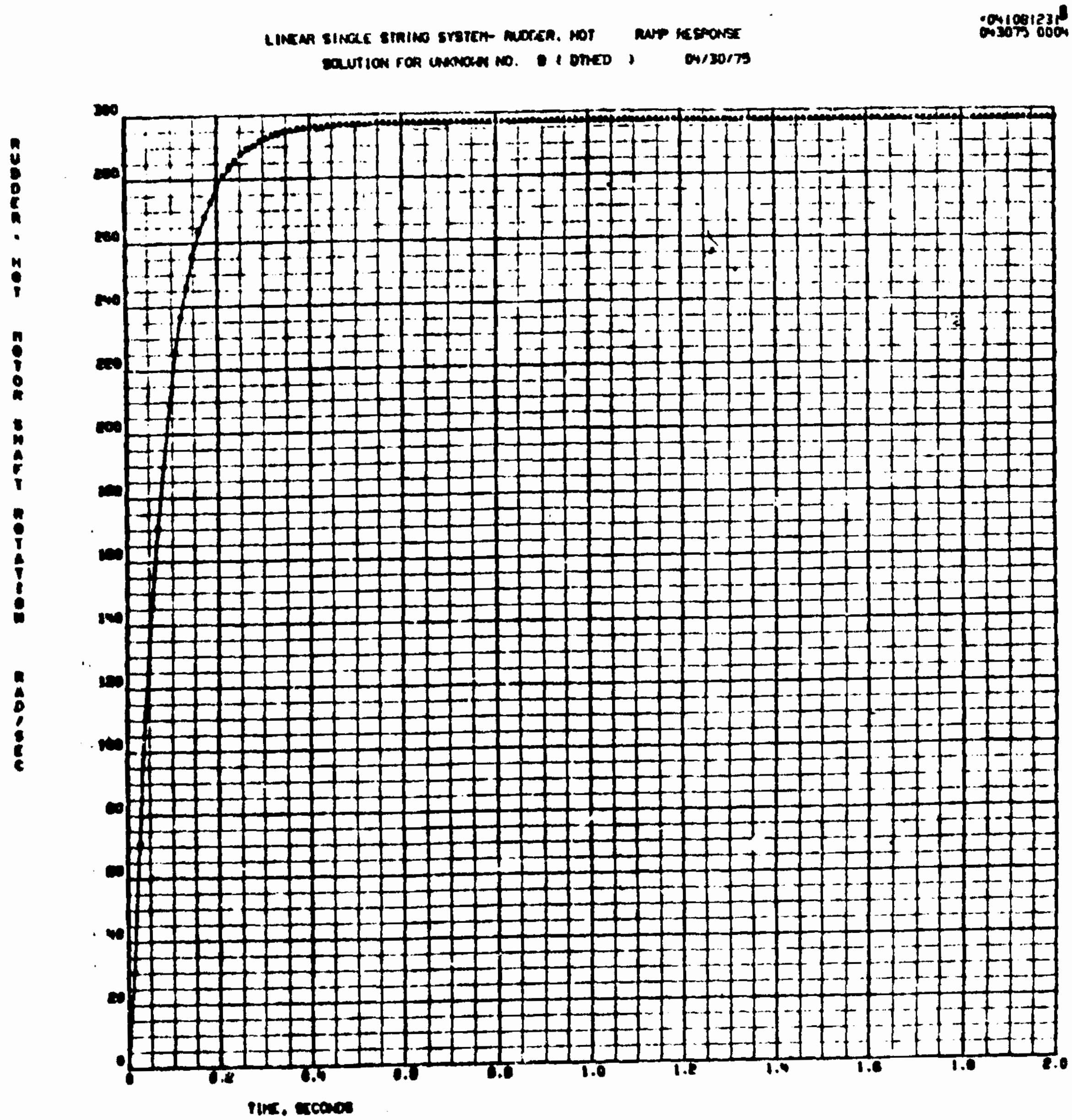


Figure D-4. – Rockwell motor speed of a single hydraulic motor for a 10.03-deg/sec Rudder input.

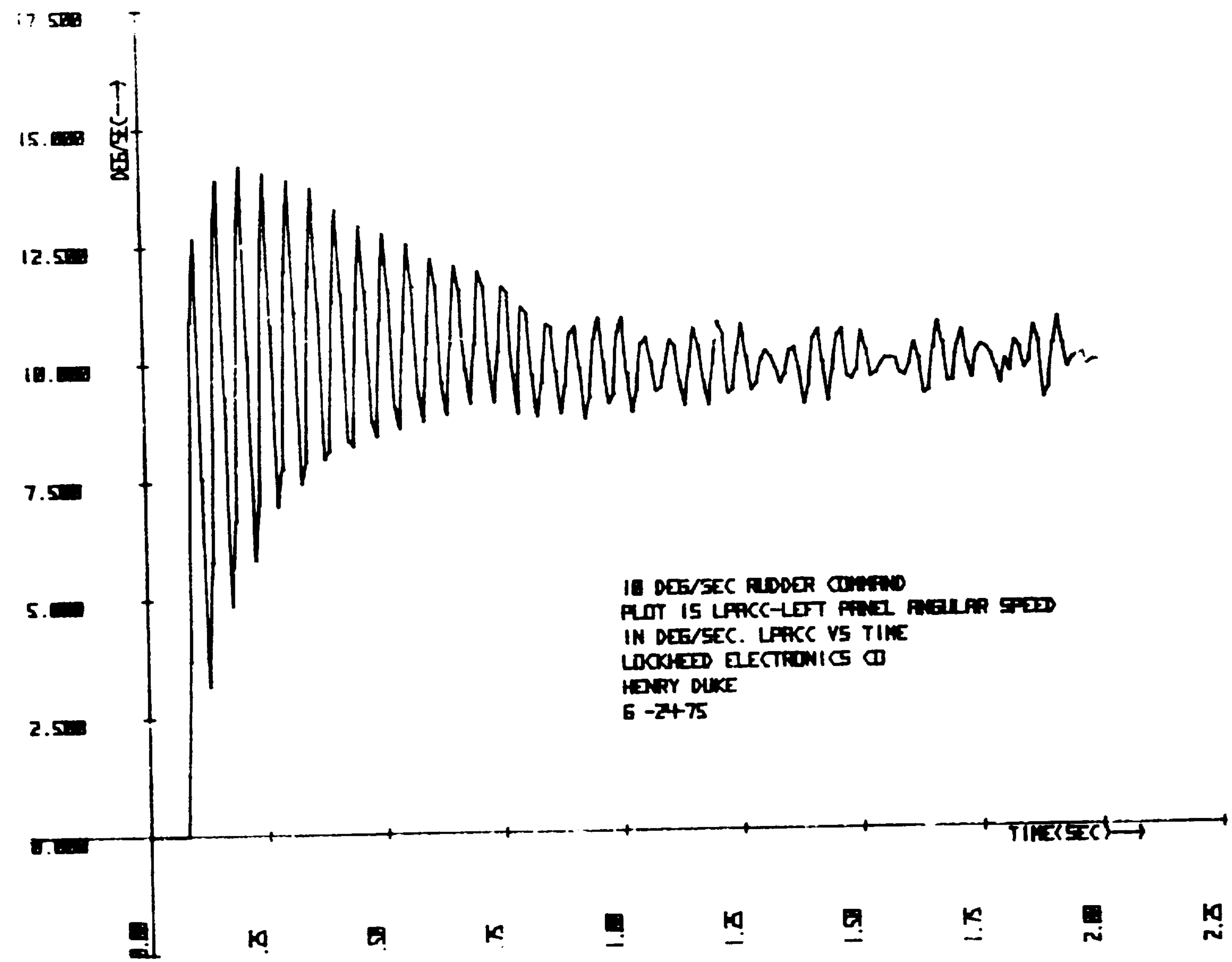


Figure D-5. – Left panel angular speed for a 10-deg/sec Rudder input.

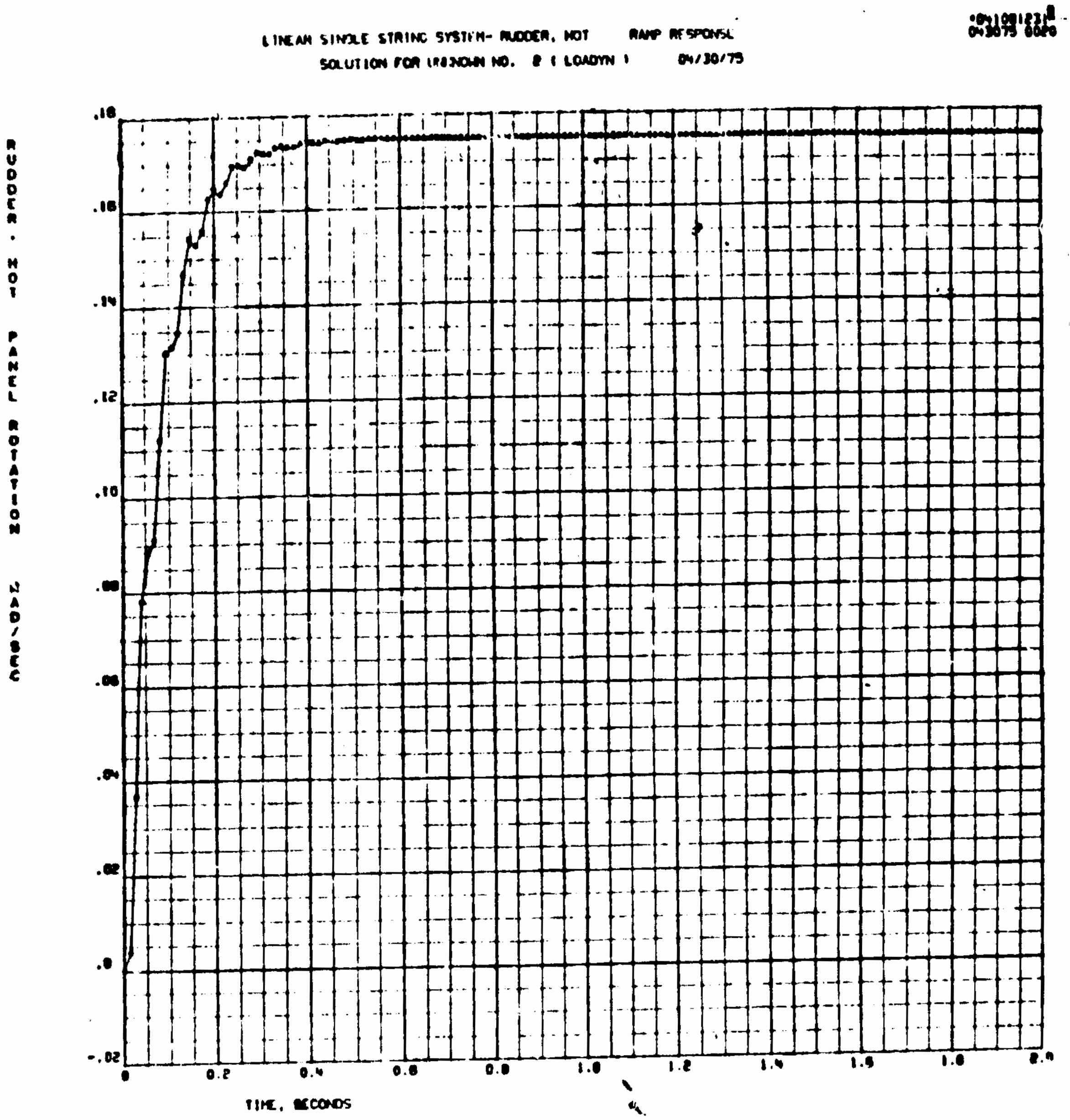


Figure D-6. — Rockwell panel speed for a 10.03-deg/sec Rudder input.

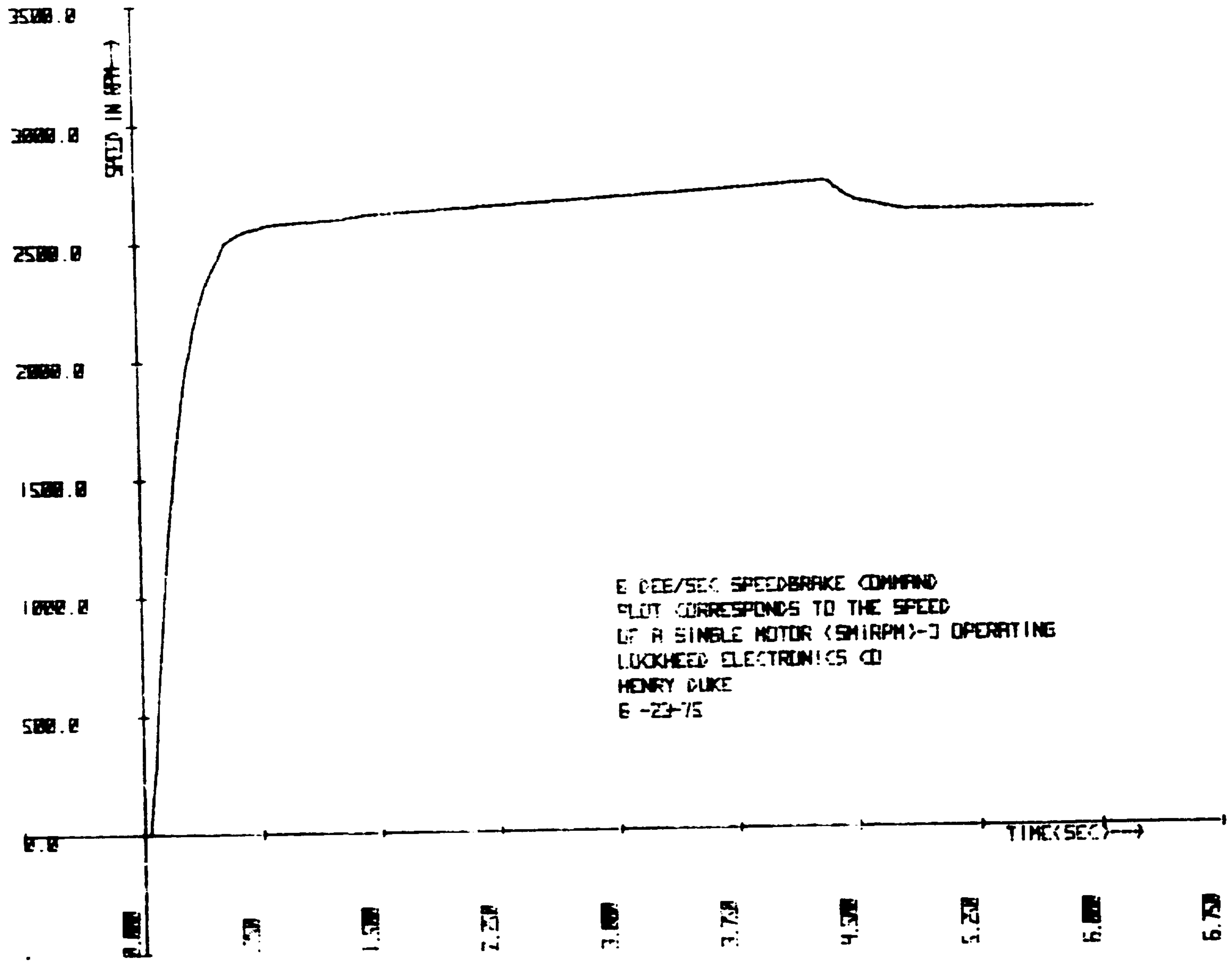


Figure D-7. – Motor speed of a single Rudder hydraulic motor for a 6-deg/sec Speedbrake command.

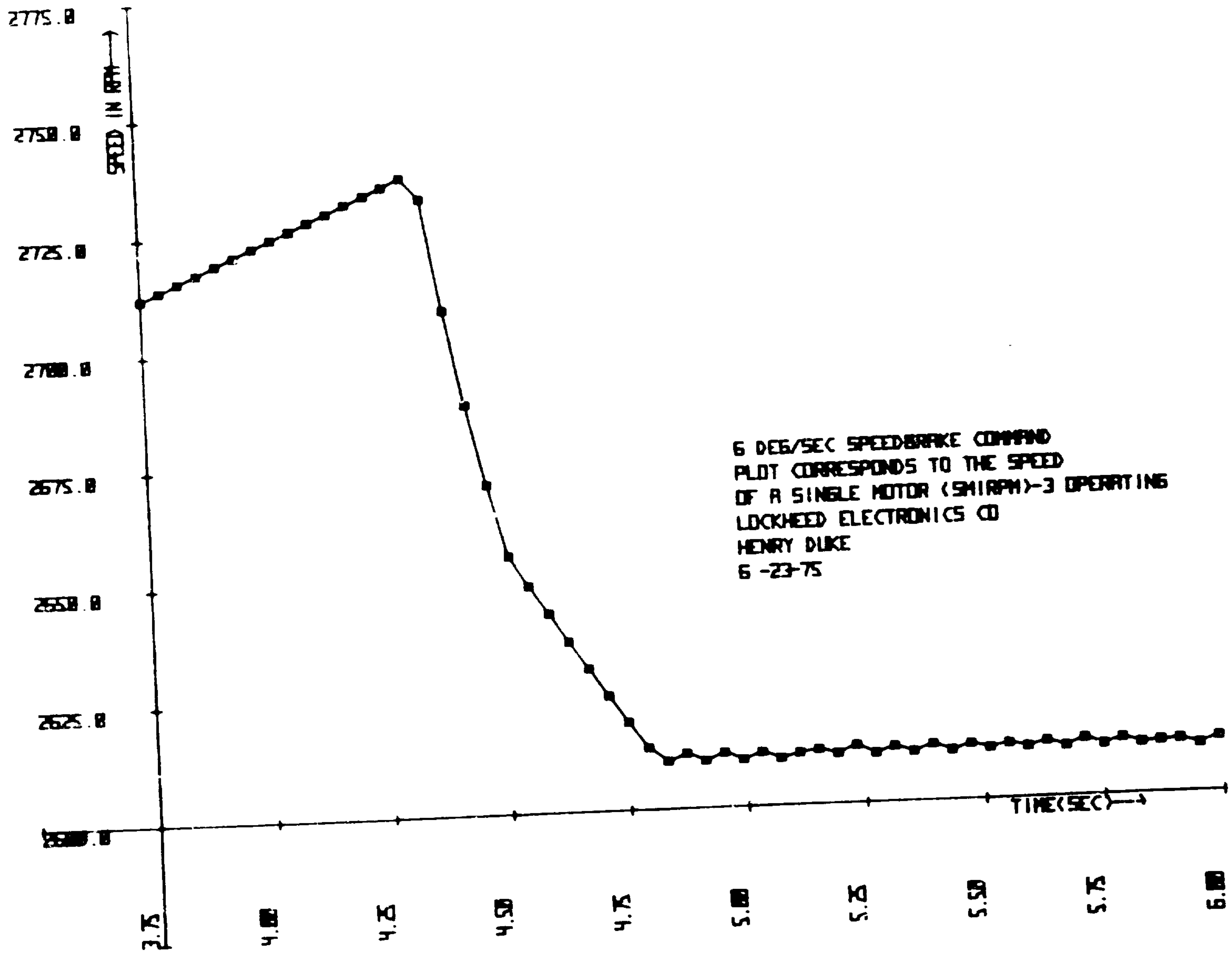


Figure D-8. – Motor speed of a single Rudder hydraulic motor for a 6-deg/sec Speedbrake command.

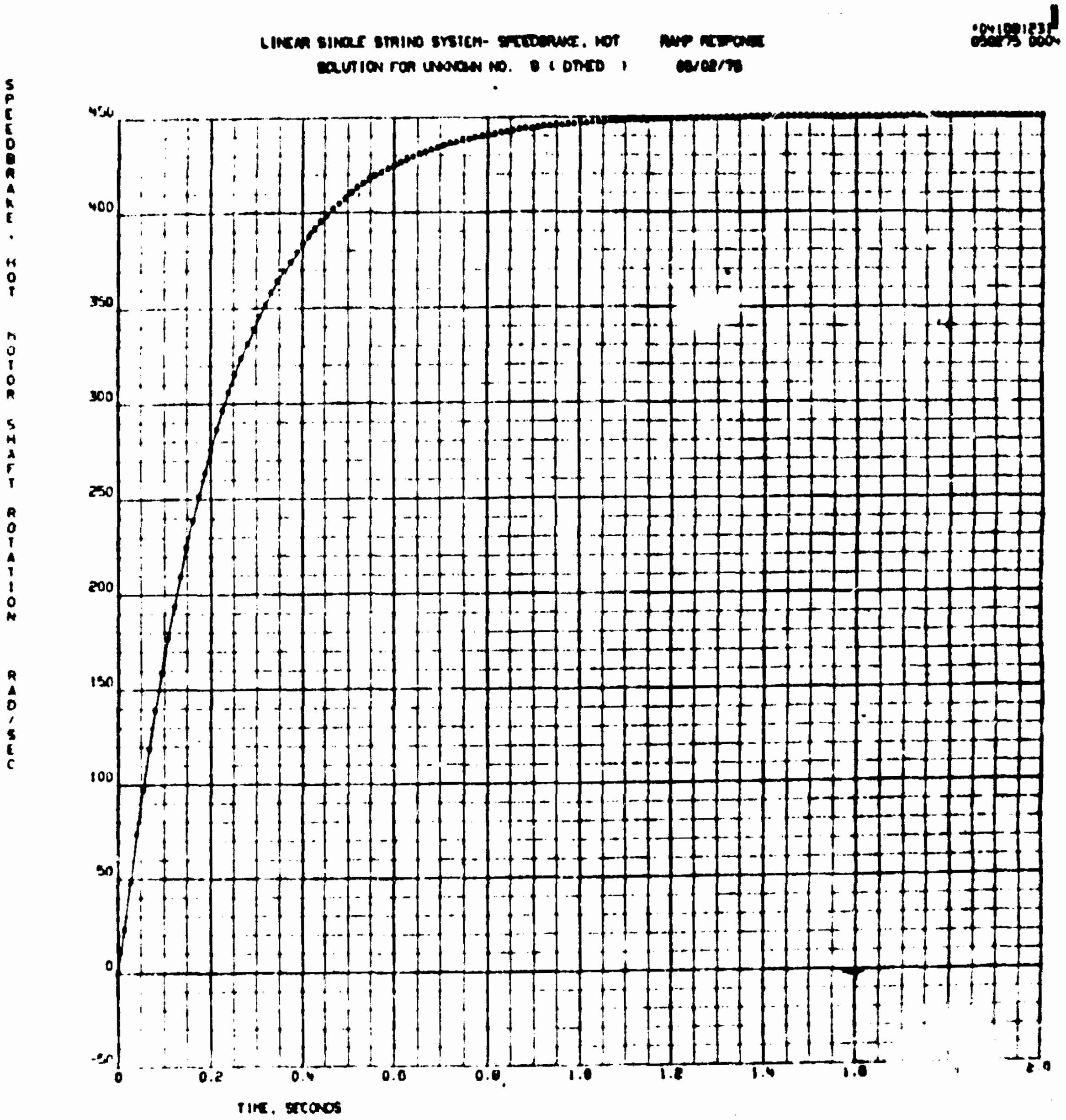


Figure D-9. – Rockwell motor speed of a single hydraulic motor for a 10.03-deg/sec Speedbrake input.

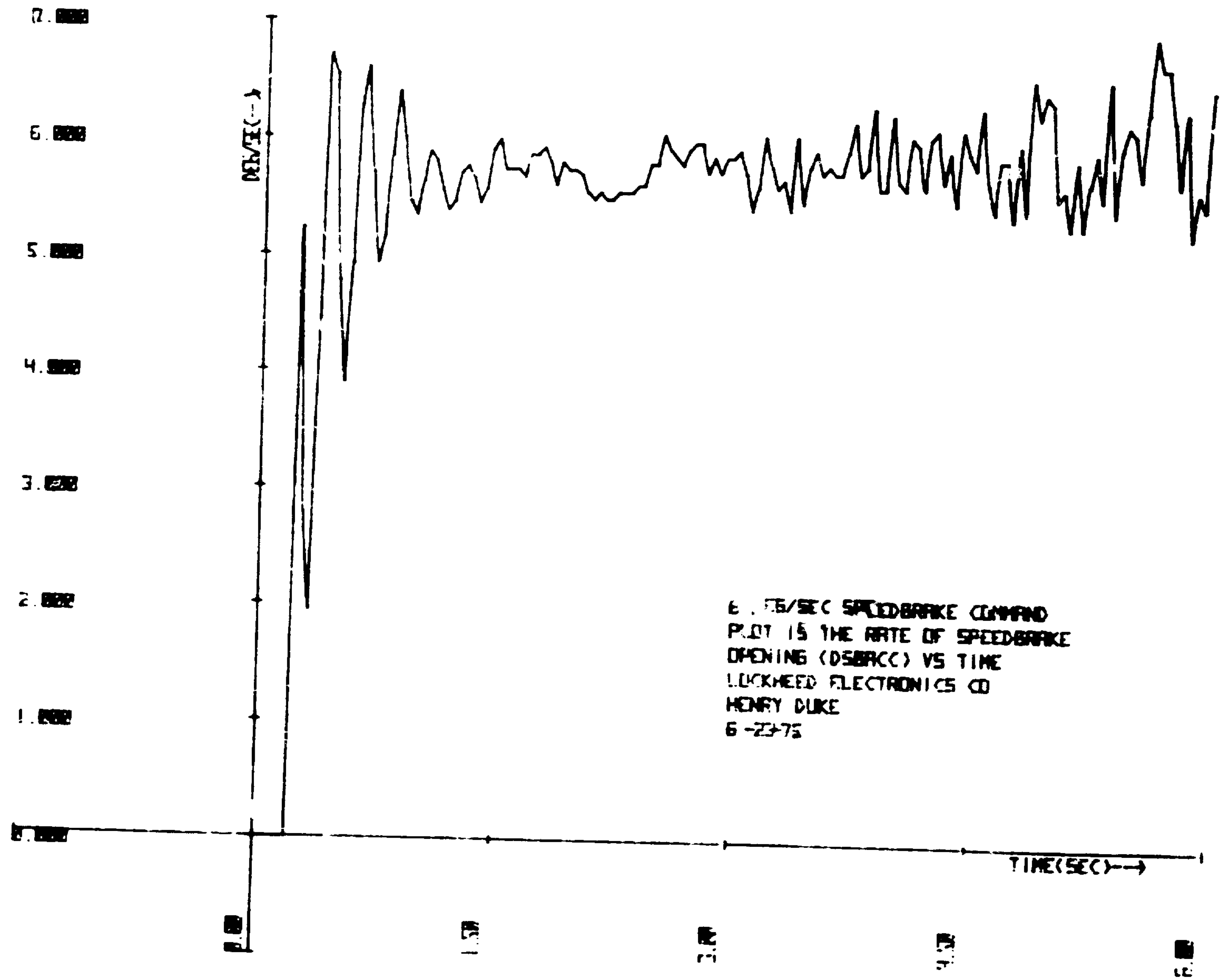


Figure D-10. – Rate of Speedbrake opening for a 6-deg/sec Speedbrake command.

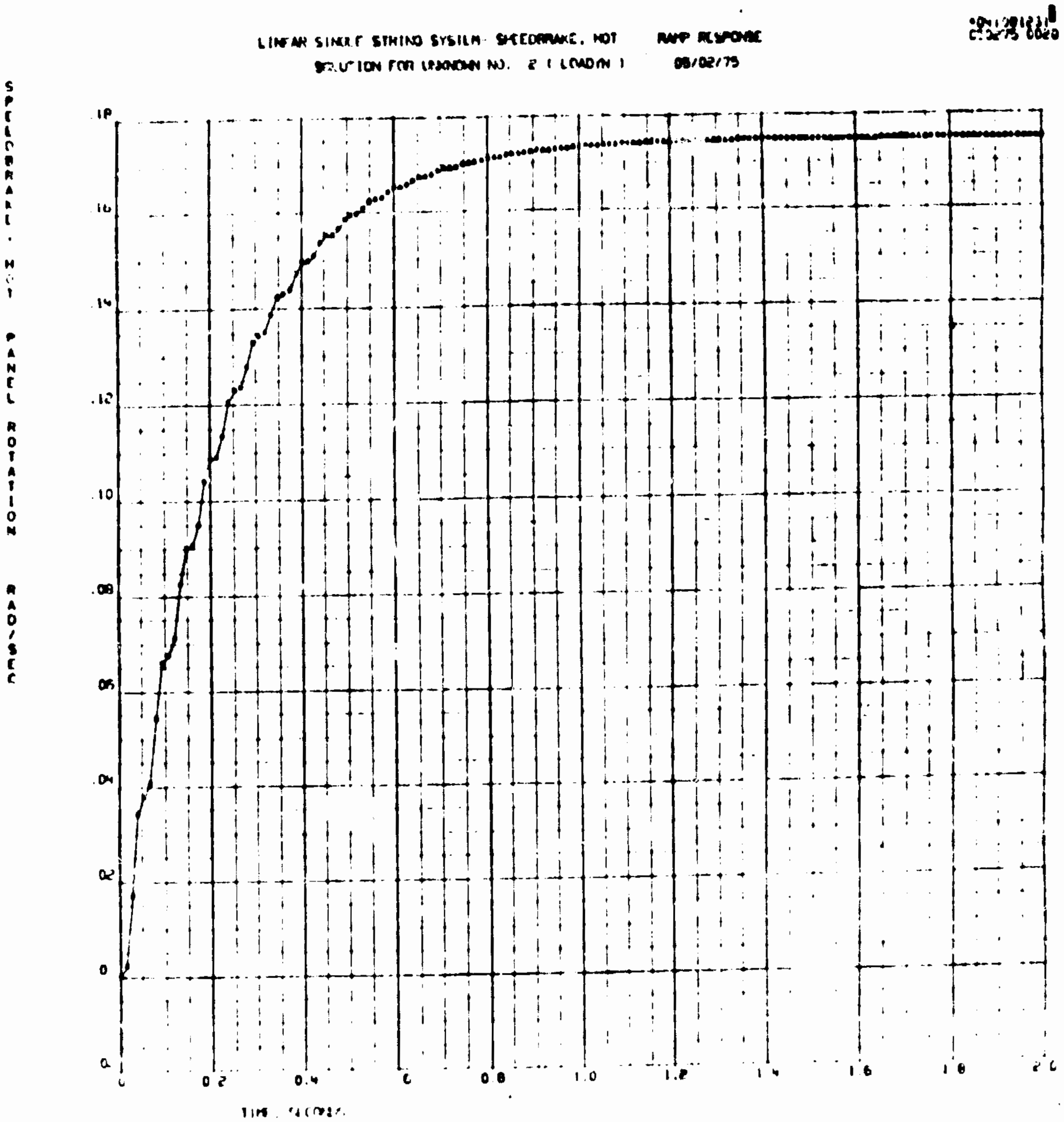


Figure D-11. - Rockwell panel opening for a 10.03-deg/sec Speedbrake input.

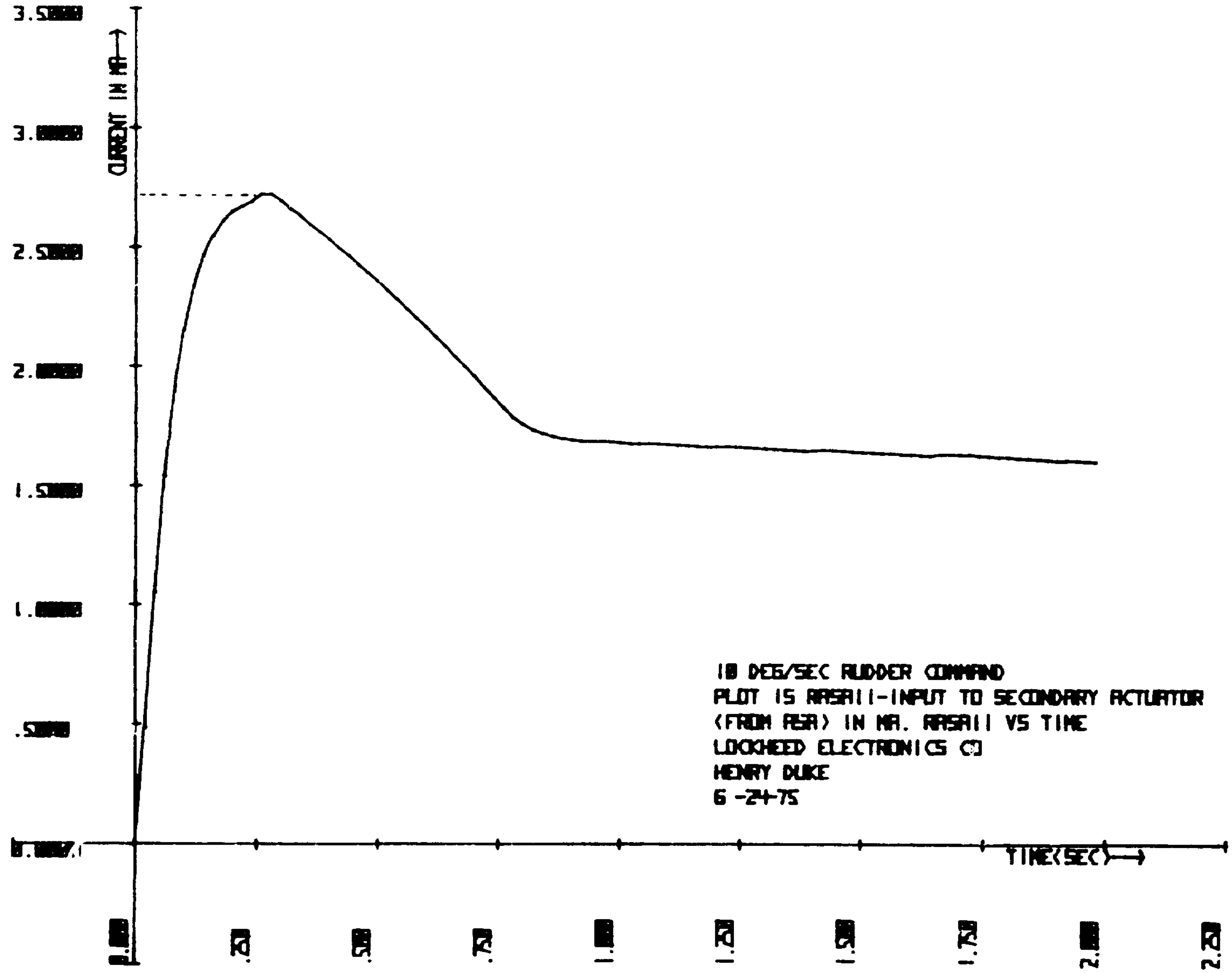


Figure D-12. - Input to secondary actuator for a 10-deg/sec Rudder input.

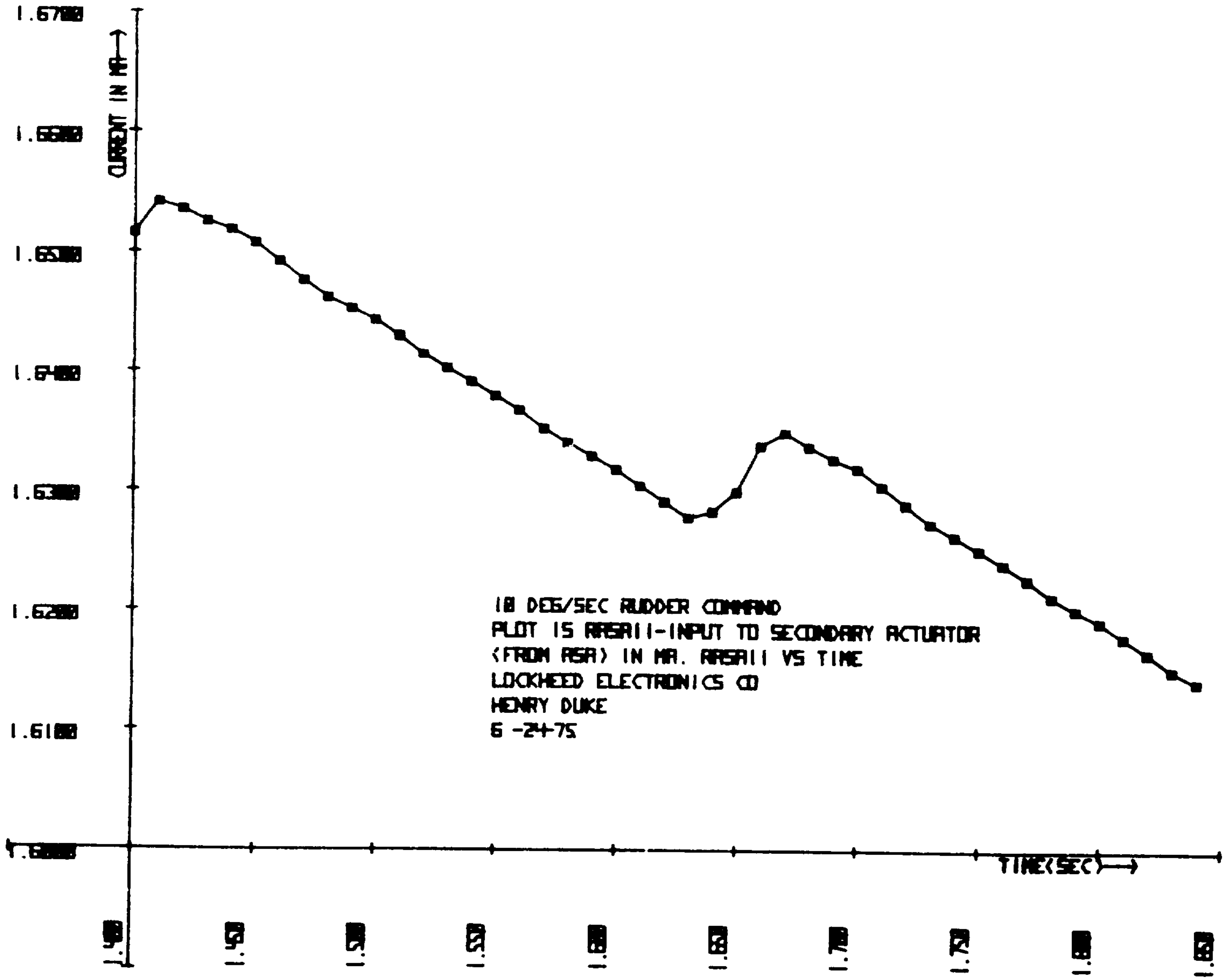


Figure D-13. – Input to secondary actuator for a 10-deg/sec Rudder input.

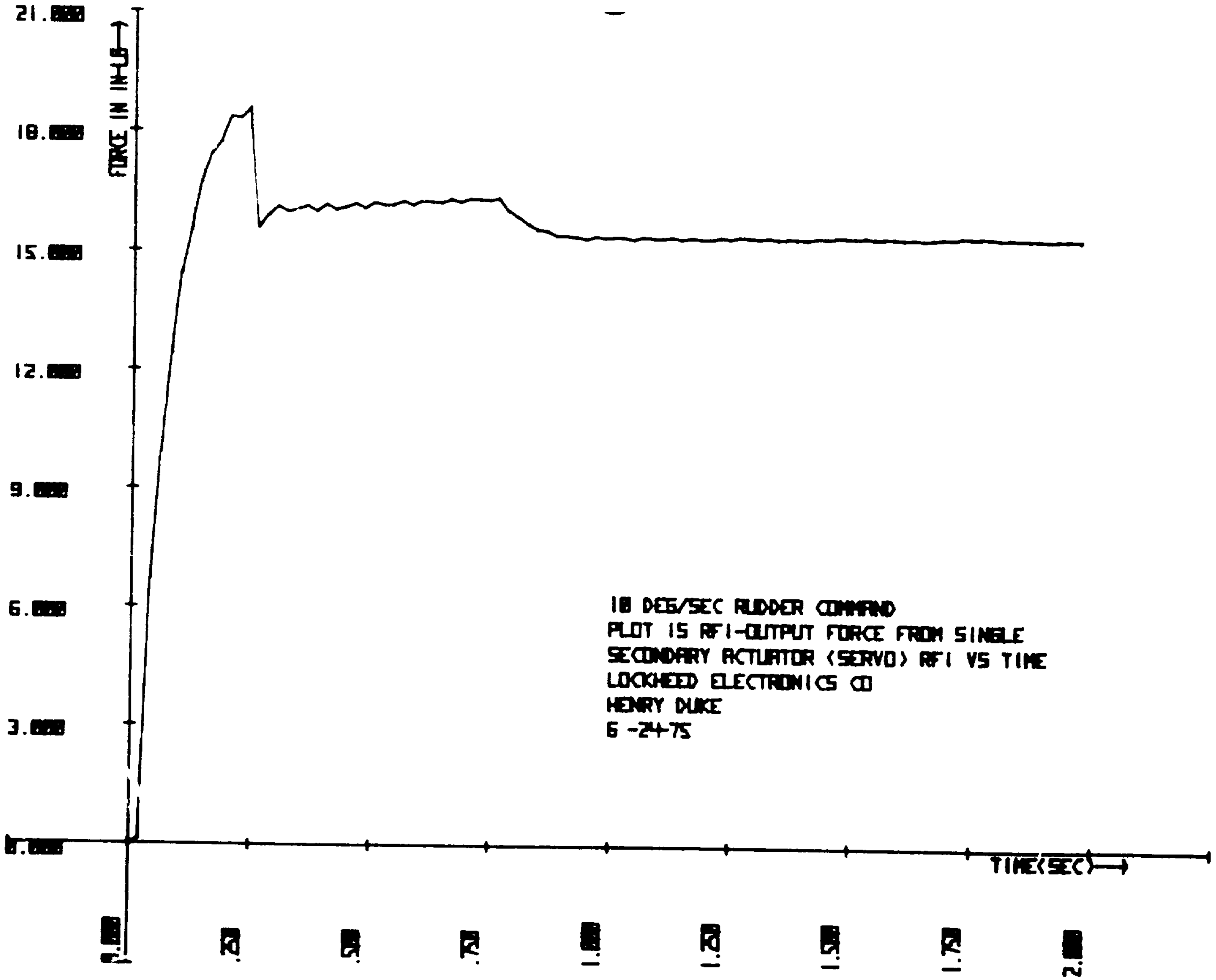


Figure D-14. - Output force from a secondary actuator for a 10-deg/sec Rudder input.

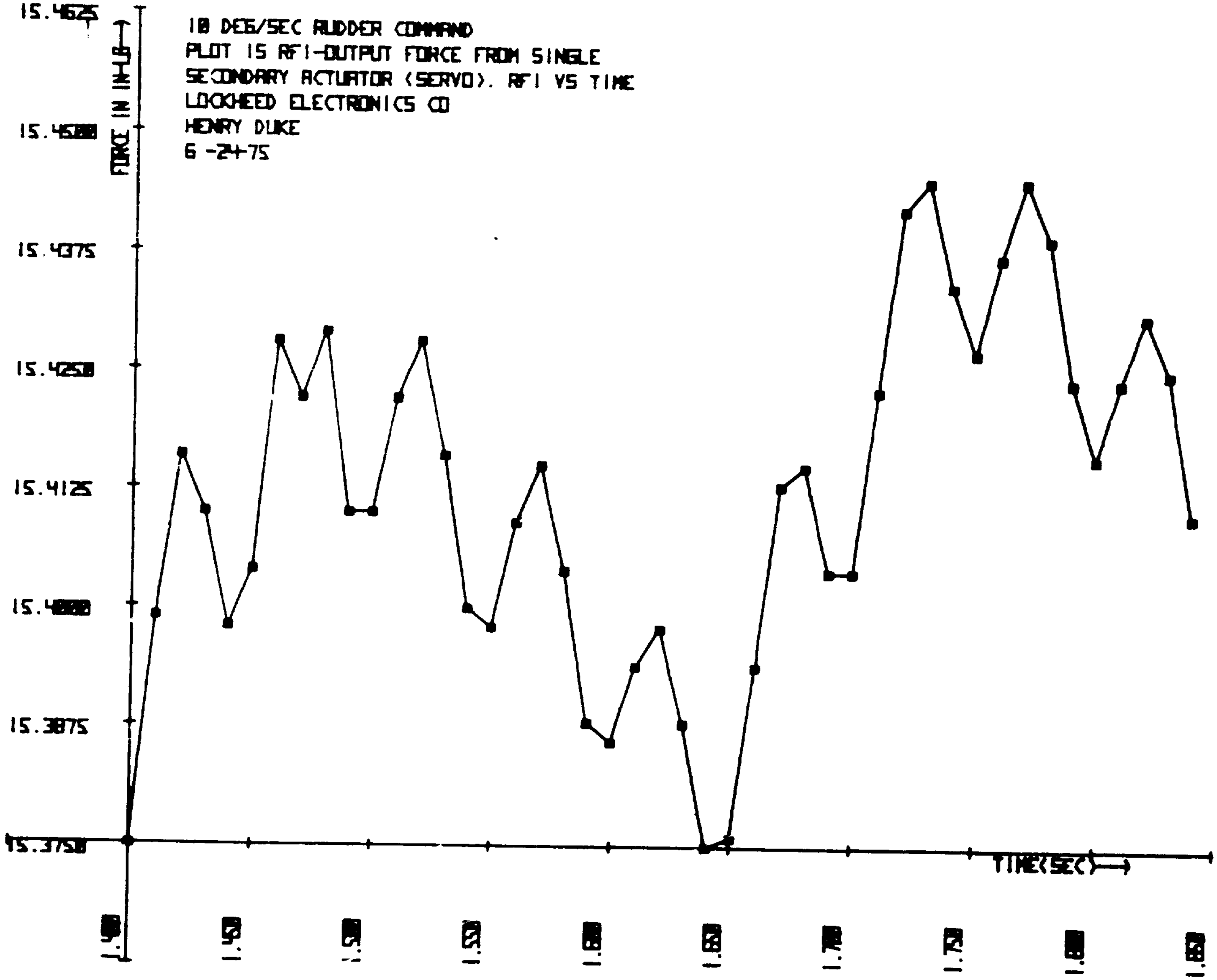


Figure D-15. — Output force from a secondary actuator for a 10-deg/sec Rudder input.

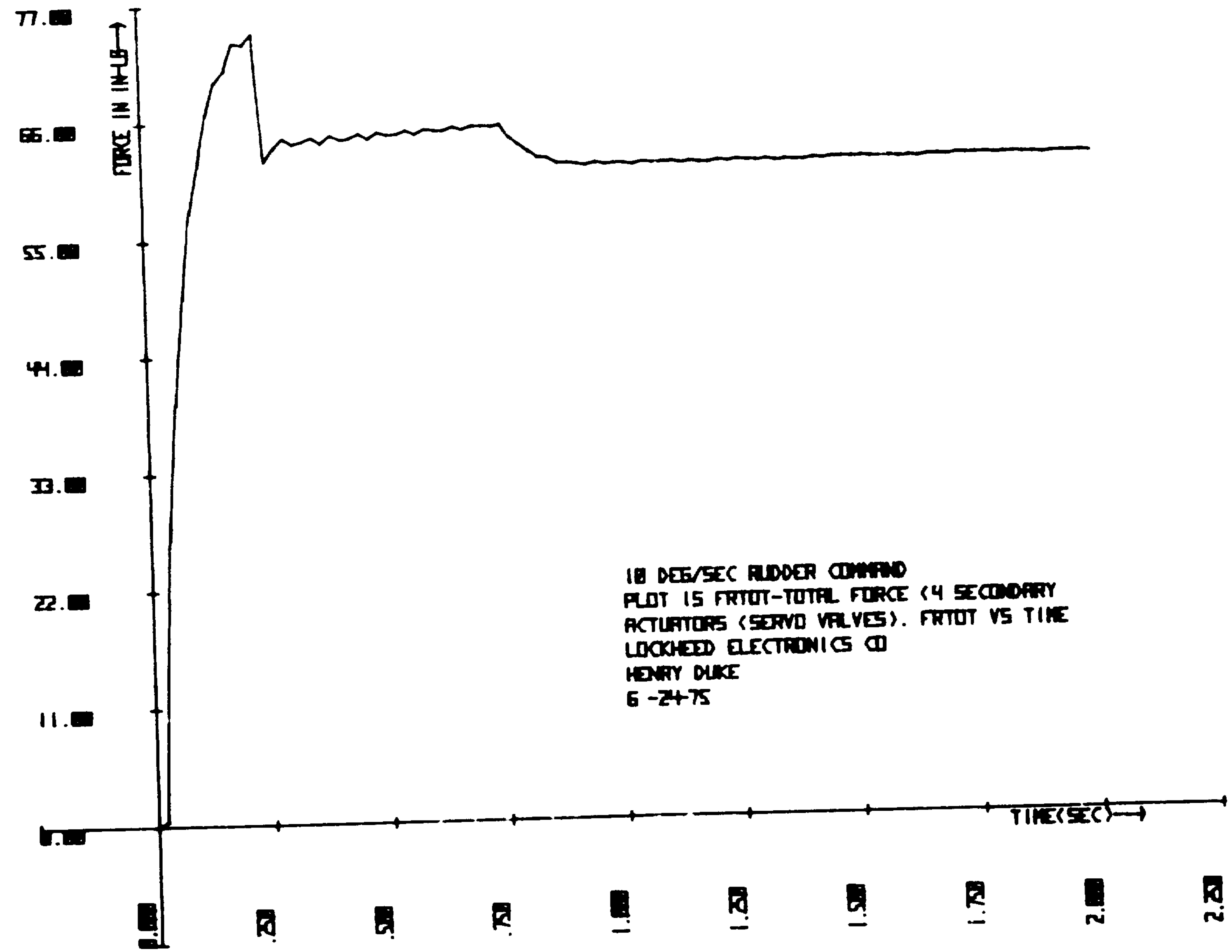


Figure D-16. — Total force output of 4 secondary actuators for a 10-deg/sec Rudder input.

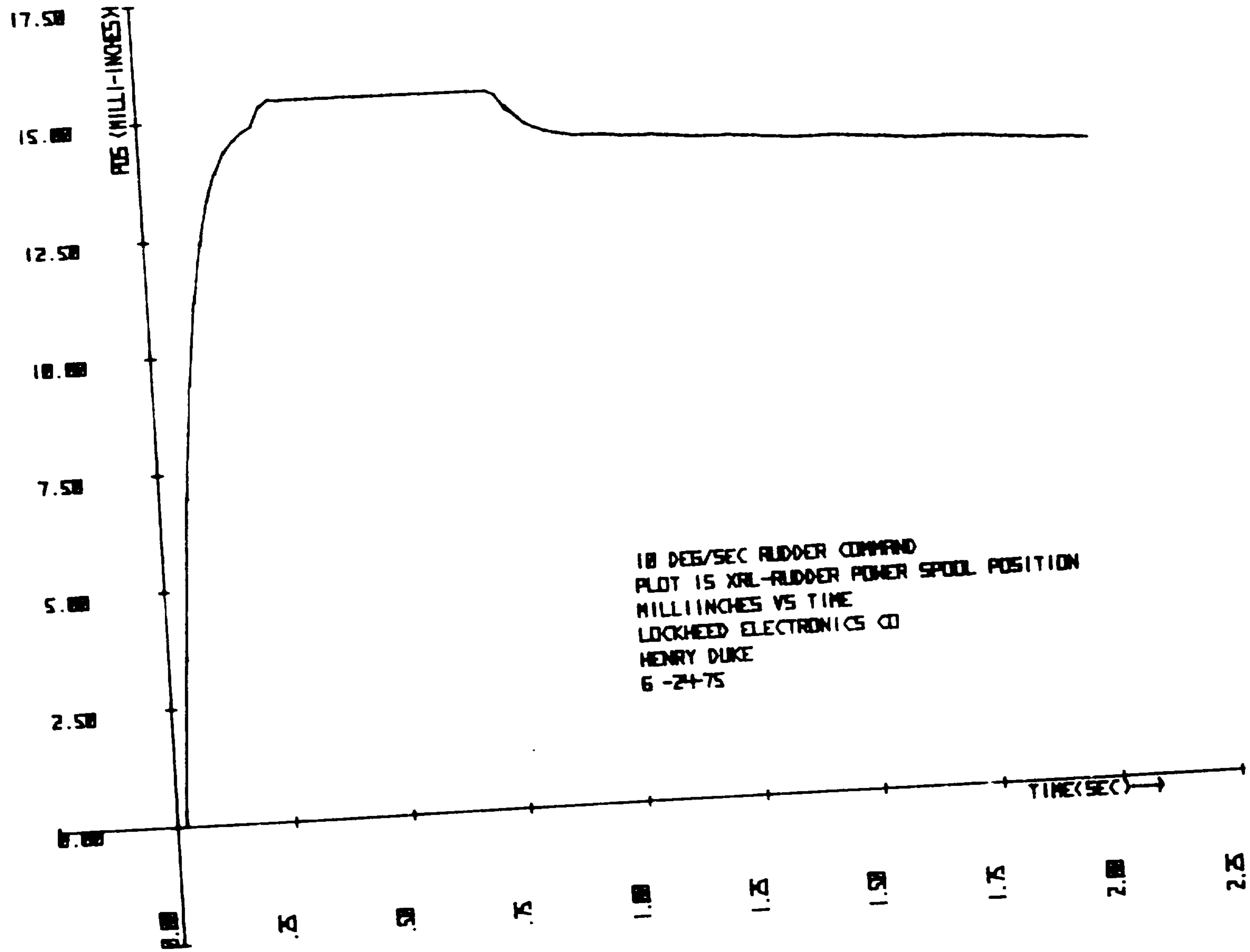


Figure D-17. – Rudder power spool position for a 10-deg/sec Rudder input.

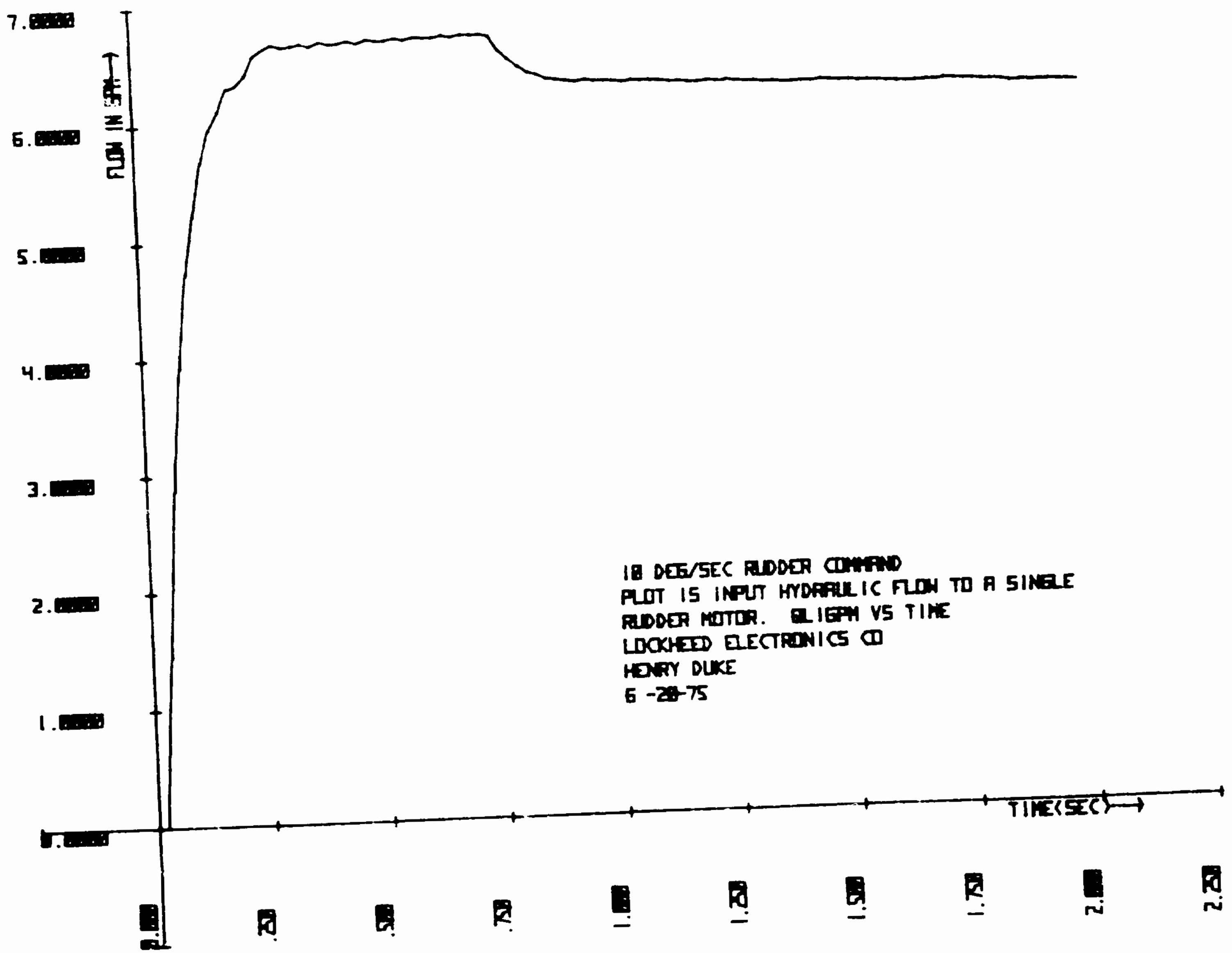


Figure D-18. – Input hydraulic flow to a single Rudder hydraulic motor for a 10-deg/sec Rudder input.

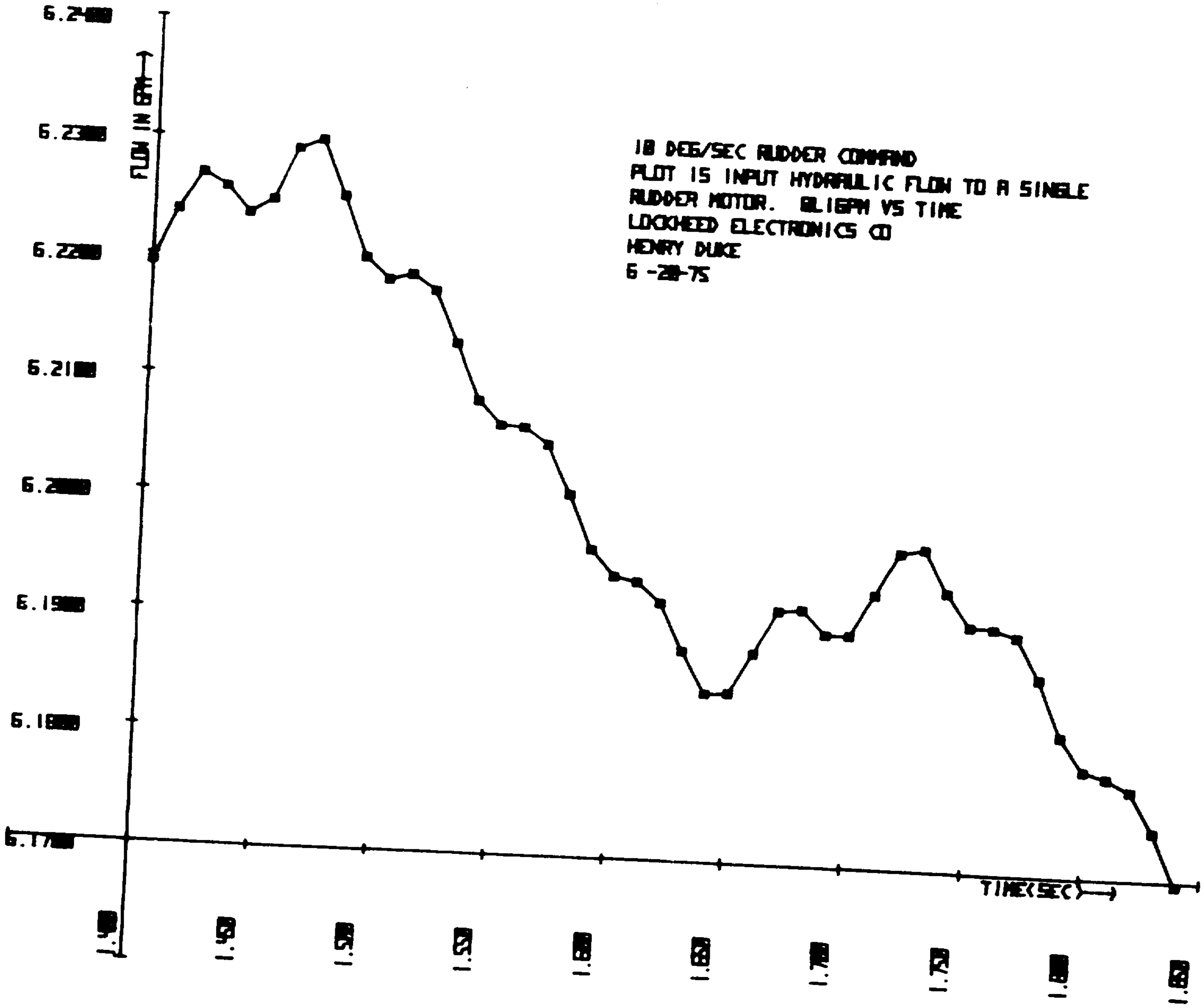


Figure D-19. – Input hydraulic flow to a single Rudder hydraulic motor for a 10-deg/sec Rudder input.

APPENDIX E

MOTOR HYDRAULIC INPUT VS MOTOR SPEED

APPENDIX E FIGURES

From ref 5, page 65, the volumetric isplacement is equal to:

$$Dm = \frac{Q_\ell}{\dot{\theta}_m} \frac{gal}{rev}$$

where:

Dm = volumetric displacement, $\frac{gal}{rev}$

Q_ℓ = flow through the motor, $\frac{in^3}{rad}$

$\dot{\theta}m$ = shaft speed of motor, $\frac{rad}{sec}$

For a shaft speed of 2853 rpm with Dm given as 0.52 (ref 1), the flow is therefore:

$$Q_\ell = Dm\ \dot{\theta}_\ell \text{ mass}$$

$$= (0.52)(2853)\ \frac{IN^3}{rev}\ \frac{rev/}{min} \times \frac{1 \text{ gal}}{231\ IN^3}$$

$$= 6.42 \text{ gpm}$$

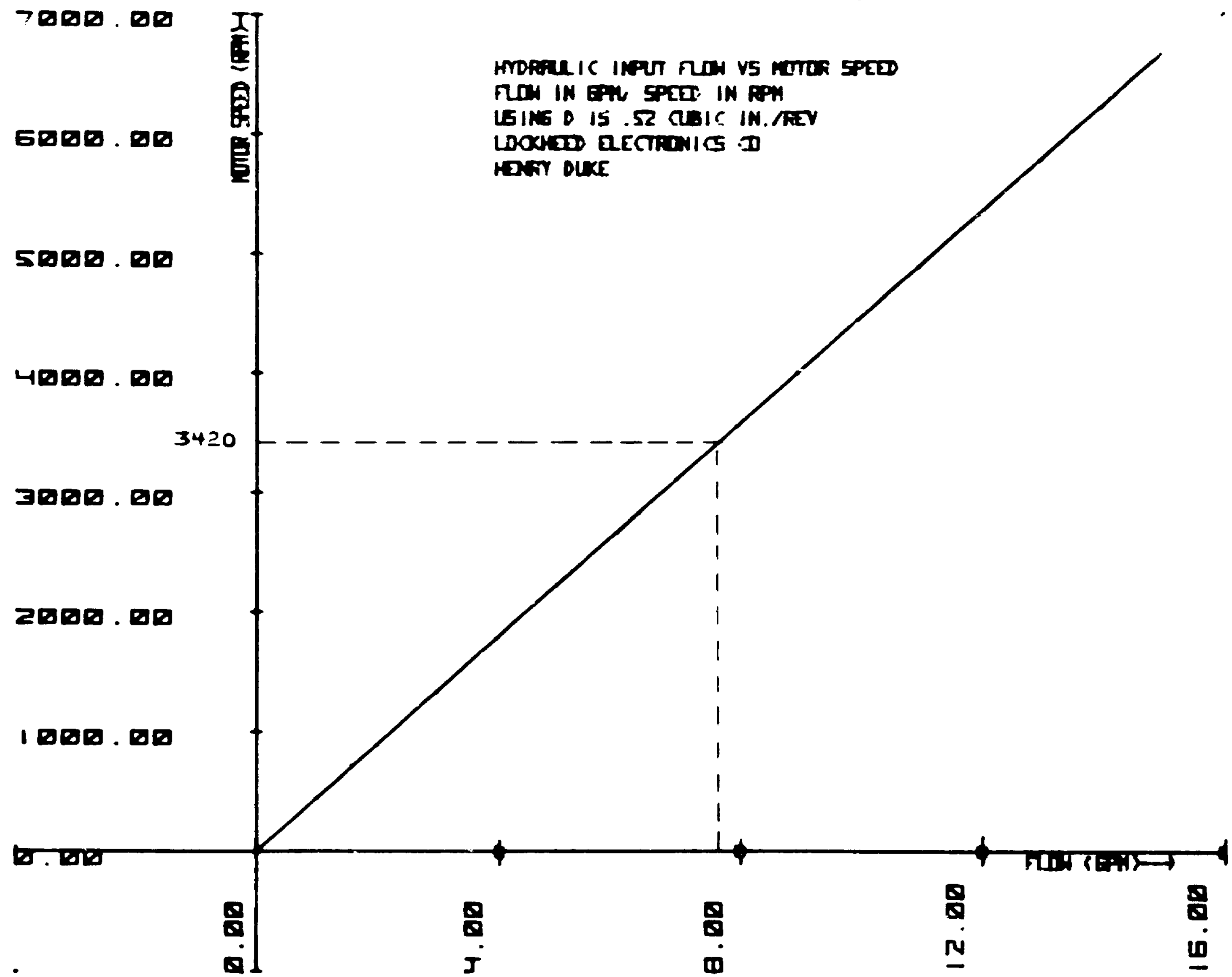


Figure E-1. – Hydraulic input flow vs motor speed.

APPENDIX F

LIST OF CSMP CONSTANTS AND VARIABLES

Sheet 1

Signature	Type	Definition	Value	Units
AC	X	AREA OF ΔP PISTON	0.008975	IN^2
AP	X	AREA OF SECOND STAGE SPOOL	0.0276	IN^2
AS	X	AREA OF MOD PISTON	0.193	IN^2
BETA	X	FLUID BULK MODULUS	1.8E5	$\frac{LB}{IN^2}$
BM	X	MOTOR VISCOUS FRICTION COEFFICIENT	0.015	IN-LB-SEC
BP	X	DAMPING, SECOND STAGE SPOOL	0.0648	$\frac{LB\text{-}SEC}{IN}$

LEGEND:
S = Speedbrake only
RD = Rudder only
X = Rudder and Speedbrake
L = Left Panel
R = Right Panel
M = Multiple use 1,2,3,4
N = Multiple use 1,2,3
V = variable, no constant value

Sheet 2

Signature	Type	Definition	Value	Units
BPP	X	VISCOUS DAMPING, EACH PANEL	15500	IN-LB-SEC
BR	X	DAMPING, TOTAL MOD PISTONS AND POWER SPOOL	1.386	$\frac{LB\text{-}SEC}{IN}$
C1	X	FLOW DISPLACEMENT COEFFICIENT OF FLAPPER NOZZLE	185.2	$\frac{IN^2}{SEC}$
C2	X	FLOW PRESSURE CHARACTERISTIC OF NOZZLE	0.1096	$\frac{IN^4}{LB\text{-}SEC}$
C3	X	FLOW PRESSURE CHARACTERISTIC OF FIXED RESTRICTION	8.76E-5	$\frac{IN^5}{LB\text{-}SEC}$
CONV	X	CONVERSION FACTOR FROM IN^3 TO GPM	0.2597	$\frac{GPM\text{-}SEC}{IN^3}$

LEGEND: S = Speedbrake only
RD = Rudder only
X = Rudder and Speedbrake
L = Left Panel
R = Right Panel
M = Multiple Use 1,2,3,4
N = Multiple Use 1,2,3
V = Variable, no constant value

Sheet 3

Signature	Type	Definition	Value	Units
CP	X	FLOW PRESSURE CHARACTERISTIC FOR SECOND STAGE SPOOL	3.03E-5	$\frac{IN^5}{LB.SEC}$
CQ	X	FLOW DISPLACEMENT CHARACTERISTIC FOR SPOOL VALUE	4.5866	$\frac{IN^3}{SEC\sqrt{LB}}$
CRPM		CONVERSION FACTOR FROM RAD/SEC TO RPM	9.5492	$\frac{RPM}{RAD/SEC}$
D	X	MOTOR VOLUMETRIC DISPLACEMENT	0.08276	$\frac{IN^3}{RAD}$
DDLP	L	RATE OF CHANGE OF PANEL MOVEMENT, PANEL SPEED	V	$\frac{RAD}{SEC}$
DDRP	R		V	$\frac{RAD}{SEC}$
DELTR	RD	SUMMER OUTPUT INCLUDING HYSTERESIS RADIAL POSITION	V	RAD
DELTS	S		V	RAD
DELTRN	RD,N	OUTPUT OF INDIVIDUAL MOTORS ACROSS SUMMER GEAR RATIO, RADIAL POSITION	V	RAD
DELTSN	S,N		V	RAD

LEGEND: S = Speedbrake Only; RD = Rudder Only; X = Rudder and Speedbrake; L = Left Panel; R = Right Panel; M = Multiple use 1,2,3,4; N = Multiple Use 1,2,3; V = Variable, no constant value

Sheet 4

Signature	Type	Definition	Value	Units
DELTXN	RD,N	POWER SPOOL OFFSET	0.0	IN.
DLP	L	LEFT AND RIGHT PANEL POSITION IN RADIANS	V	RADIANS
DRP	R			
DRFRL	RD	ANGLE BETWEEN LEFT AND RIGHT HAND PANELS IN FRL	V	DEGREES (FRL)
DSBFRL	S			
DRRHL	RD	ANGLE BETWEEN LEFT AND RIGHT HAND PANELS IN RHL	V	DEGREES (RHL)
DSBRHL	S			

LEGEND:
S = Speedbrake Only
RD = Rudder Only
X = Rudder and Speedbrake
L = Left Panel
R = Right Panel
M = Multiple Use 1,2,3,4
N = Multiple Use 1,2,3
V = Variable, No Constant value

Sheet 2

Signature	Type	Definition	Value	Units
DRVLM	RD,M	DERIVATIVE OF RVLM	V	--
DSVLM	S,M			
DRMXM	RD,M	DERIVATIVE OF RMXM	V	--
DSMXM	S,M			
DSBACC	S	SPEEDBRAKE PANEL SEPARATION SPEED IN RHL	V	DEGREES/SECOND
DSBXN	S,N	SPEEDBRAKE POWER SPOOL OFFSET	0.0	INCHES
EG	X	EFFICIENCY FACTOR FOR MIXER, SUMMER AND PDU GEARS	0.7872	--
F3	L	STATIC AND COULOMB FRICTION ON PANELS	0.0	IN-LB
F4	R		0.0	IN-LB

LEGEND:
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L = Left Panel
R = Right Panel
M = Multiple Use 1,2,3,4
N = Multiple Use 1,2,3
V = Variable, No Constant Value

Sheet 6

Signature	Type	Definition	Value	Units
FR	RD	POWER SPOOL POSITION ERROR	V	LB
PS	S			
FRC	X	POWER SPOOL STATIC AND COULOMB STARTING FRICTION	13.0	LB.
FRL	X	FUSILAGE REFERENCE LINE	--	--
FRTOT	RD	TOTAL OUTPUT FORCE FROM 4 SERVO VALUES	V	LB.
FSTOT	S			
G1	X	FLOW PRESSURE CHARACTERISTIC USED IN SPOOL VALUE TO REPRESENT SUM OF FIXED RESTRICTION AND NOZZLE FLOW PRESSURE CHARACTERISTICS	59.24	$\frac{IN^5}{LB\text{-}SEC}$
G2	X	SECOND STAGE SERVO VALUE VOLUMETRIC REACTION TO FIRST STAGE PRESSURE DRIVE	$1.72E^{-6}$	$\frac{IN^3}{P.S.I.}$
GH	X	POWER HINGE GEAR RATIO	473.921:1	--

LEGEND: S -Speedbrake Only
RD = Rudder Only
X = Rudder and Speedbrake
L = Left Panel
R = Right Panel
M = Multiple Use 1,2,3,4
N = Multiple Use 1,2,3
V = Variable, No Constant Value

Sheet 7

Signature	Type	Definition	Value	Units
GMR	RD	MIXER GEAR TRAIN RATIO	1.47:1	--
GMS	S		4.46:1	--
HH	X	POWER HINGE HYSTERISIS	2.9088-E-3	RAD
HINGE	X	HINGE MOMENT RAMP FUNCTION	V	IN.LB / DEG
HLP	L	HINGE MOMENT	V	IN.LB.
HRP	R			
HMLP	L	HINGE MOMENT	V	IN.LB.
HMRP	R			
HMR	RD	MIXER GEAR TRAIN HYSTERESIS	0.0208	RAD
HMSB	S		0.0208	RAD
IL	X	CURRENT LIMIT OF FLAPPER TORQUE MOTOR IN SERVO VALVE	8.0	mA

LEGEND:
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L = Left Panel
R = Right Panel
M = Multiple Use 1,2,3,4
N = Multiple Use 1,2,3
V = Variable, No Constant Value

Sheet 8

Signature	Type	Definition	Value	Units
JMR	RD	MOTOR MOMENT OF INERTIA	0.00636	IN-LB-SEC^2
JMS	S		0.00565	IN-LB-SEC^2
JP	X	MOMENT OF INERTIA OF INDIVIDUAL PANEL	2579.0	IN-LB-SEC^2
KAMP	X	ASA GAIN	17.5	$\frac{mA}{VOLT}$
KB	X	BERNOULLI FORCE COEFFICIENT	0.52	IN.
KC	X	DYNAMIC LOAD DAMPING GAIN	1.91617	$\frac{mA}{VOLT}$
KFB	RD	ACTUATOR POSITION TRANSDUCER GAIN	10.571177	$\frac{VOLTS}{RADIAN}$
KFBSB	S		5.81093	$\frac{VOLTS}{RADIAN}$

LEGEND: S = Speedbrake Only; RD = Rudder Only; X = Rudder and Speedbrake; L=Left Panel; R = Right Panel; M = Multiple Use 1,2,3,4; N = Multiple Use 1,2,3; V= Variable, No Constant Value

Sheet 9

Signature	Type	Definition	Value	Units
KFL	X	FLAPPER VALUE LIMITS OF SECONDARY ACTUATOR	0.0011	IN.
KHC	X	SPRING CONSTANT OF ROTARY ACTUATORS	0.397E+8	$\frac{\text{IN-LB}}{\text{RAD}}$
KHST	X	HYSTERESIS CONSTANT FOR TORQUE MOTOR-COIL HYSTERESIS	0.02	IN-LB
KN	X	NOZZLE PRESSURE FEEDBACK CONSTANT	1.38E-4	IN^3
KP	X	TOTAL SPRING RATE OF SECOND STAGE SPOOL	1200.0	$\frac{\text{LB.}}{\text{IN.}}$
KPQ	X	MOTOR LEAKAGE COEFFICIENT	0.004	$\frac{IN^5}{\text{LB-SEC}}$

LEGEND: S = Speedbrake Only
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X = Rudder and Speedbrake
L = Left Panel
R = Right Panel
M = Multiple Use 1,2,3,4
N = Multiple Use 1,2,3
V = Variable, No Constant Value

Sheet 10

Signature	Type	Definition	Value	Units
KPT	X	PRESSURE TRANSDUCER GAIN	0.00167	$\frac{VOLTS}{PSI}$
KQP	X	RUDDER POWER SPOOL FLOW GAIN	33.2	$\frac{IN^2}{SEC\sqrt{LB}}$
KR	RD	CONSTANT TO CONVERT RHL TO FRL FOR PANEL ANGLE (RUDDER) OR INCLUDED ANGLE (SPEEDBRAKE)	0.841328	--
KSB	S		0.88438	--
KFBL	X	FEEDBACK GAIN FROM POWER SPOOL POSITION	6.22	$\frac{IN-LB}{IN.}$
KRV	RD	CHANGE DEGREES INPUT COMMAND TO VOLTS	0.1845	$\frac{VOLTS}{DEGREE}$
KSBV	S		0.10142	$\frac{VOLTS}{DEGREE}$
KTM	X	CHANGE INPUT CURRENT TO TORQUE. TRANSLATIONAL GAIN OF TORQUE MOTOR IN SERVO	0.045	$\frac{IN-LB}{mA}$

LEGEND: S = Speedbrake Only
RD = Rudder Only
X = Rudder and Speedbrake
L = Left Panel
R = Right Panel
M = Multiple Use 1,2,3,4
N = Multiple Use 1,2,3
V = Variable, No Constant Value

Sheet 11

Signature	Type	Definition	Value	Units
LBP	L	POWER HINGE DAMPED FEEDBACK	V	IN-LB RADIANS
RBP	R		V	IN-LB RADIANS
LD	X	DEMODULATOR FILTER DAMPING FACTOR (TIMES 2)	0.707	--
LDL	L	POWER HINGE DYNAMICS POSITION ERROR	V	IN-LB-RADIANS
RDL	R		V	IN-LB-RADIANS
LN	X	FLAPPER POSITION GAIN	0.01693	$\frac{\text{IN.}}{\text{IN-LB.}}$
LPACC	L	PANEL SPEED (RHL)	V	$\frac{\text{DEG}}{\text{SEC}}$
RPACC	R			
LPDEG	L	PANEL ANGULAR POSITION (RHL)	V	DEG
RPDEG	R			

LEGEND: S = Speedbrake Only
RD = Rudder Only
X = Rudder and Speedbrake
L = Left Panel
R = Right Panel
M = Multiple Use 1,2,3,4
N = Multiple Use 1,2,3
V = Variable, No Constant Value

Sheet 12

Signature	Type	Definition	Value	Units
MP	X	SECOND STAGE SPOOL MASS IN SERVO VALVE	6.83E-5	$\frac{LB\text{-}SEC^2}{IN}$
MR	X	TOTAL MASS MOD PISTONS IN SERVO VALVE	2.07E-3	$\frac{LB\text{-}SEC^2}{IN}$
PDU	X	POWER DRIVE UNIT	--	--
PLN	RD,N	PRESSURE OUTPUT FROM POWER SPOOL TO MOTOR. PRESSURE DROP ACROSS MOTOR	V	PSI
PSLN	S,N		V	PSI
PLNLIM	RD,N	MOTOR INPUT PRESSURE LIMITER	V	PSI
PSLNLIM	S,N		V	PSI
PSN	X,N	HYDRAULIC INPUT PRESSURE TO RUDDER/SPEED-BRAKE SUBSYSTEM	2800	PSI
R1XM	RD,M	SERVO 2ND STAGE FLOW FEEDBACK FROM SERVO MOD PISTON	V	IN^3/SEC
S1XM	S,M		V	IN^3/SEC

LEGEND: S = Speedbrake Only
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L = Left Panel
R = Right Panel
M = Multiple Use 1,2,3,4
N = Multiple Use 1,2,3
V = Variable, No Constant Value

Sheet 13

Signature	Type	Definition	Value	Units
LPHHS	L	OUTPUT OF POWER HINGE HYSTERESIS. UNLOADED PDU POSITION	V	RADIANS
RPHHS	R		V	RADIANS
LPHIN	L	INPUT TO POWER HINGE HYSTERESIS	V	RADIANS
RPHIN	R		V	RADIANS
LPHS	L	ERROR BETWEEN DRIVE POSITION LPHHS OR RPHHS AND ACTUAL POSITION FEEDBACK DLP AND DRP	V	RADIANS
RPHS	R		V	RADIANS
LPMIX	L	OUTPUT OF MIXER GEAR HYSTERESIS	V	RADIANS
RPMIX	R		V	RADIANS
LPX	L	INPUT TO MIXER GEAR HYSTERESIS	V	RADIANS
RPX	R		V	RADIANS
LTPC	L	FEEDBACK FROM LOAD DYNAMICS STICTION SWITCH	V	IN-LB-RADIANS
RTPC	R		V	IN-LB-RADIANS

LEGEND: S = Speedbrake Only L = Left Panel V = Variable, No Constant Value
RD = Rudder Only R = Right Panel
X = Rudder and Speedbrake M = Multiple Use 1,2,3,4
N = Multiple Use 1,2,3

Sheet 14

Signature	Type	Definition	Value	Units
RAD	X	CONVERT RADIANS TO DEGREES	57.29578	$\frac{DEG}{RAD}$
RASAI$\underline{M}$	RD,M	SECONDARY DELTA P FEEDBACK ERROR	V	mA
SASAI$\underline{M}$	S,M		V	mA
[illegible]	RD,M	FLOW DISPLACEMENT CHARACTERISTIC OF SERVO MOD PISTON	V	$\frac{IN^2}{SEC}$
S$\underline{M}$QO	S,M		V	$\frac{IN^2}{SEC}$
RBF$\underline{N}$	RD,N	BERNOVLLI FORCE FEEDBACK	V	LB
SBF$\underline{N}$	S,N		V	LB
PV$\underline{N}$	RD,N	POWER SPOOL INPUT PRESSURE	V	PSI
SPV$\underline{N}$	S,N		V	PSI

LEGEND: S = Speedback Only; RD = Rudder Only; X = Rudder and Speedbrake; L = Left Ranel; R = Right Panel; M = Multiple Use 1,2,3,4; N = Multiple Use 1,2,3; V = Variable, No Constant Value

Sheet 15

Signature	Type	Definition	Value	Units
RDDSPM	RD,M	SECOND DERIVATIVE OF INTERNAL FORCE OF SERVO 2ND STAGE SPOOL	V	--
SDDSPM	S,M		V	--
RDDVWM	RD,M	SECOND DERIVATIVE OF RUDDER (OR SPEED-BRAKE) SECONDARY DELTA P FEEDBACK	V	--
SDDVWM	S,M		V	--
RDDVZM	RD,M	SECOND DERIVATIVE OF RUDDER (OR SPEED-BRAKE) POSITION FEEDBACK	V	--
SDDVZM	S,M		V	--
RDEGM	RD,M	INPUT CONSTANT - USED AS CONSTANT STEP COMMAND	AR	--
SDEGM	S,M		AR	--
RDSPM	RD,M	SECOND DERIVATIVE OF RUDDER (OR SPEED-BRAKE) SERVO MOD PISTON FORCE INPUT	V	--
SDSPM	S,M		V	--
RDVWM	RD,M	1ST DERIVATIVE OF RUDDER (OR SPEEDBRAKE) SECONDARY DELTA P FEEDBACK	V	--
SDVWM	S,M		V	--

LEGEND:
S = Speedbrake Only
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M = Multiple Use 1,2,3,4
N = Multiple Use 1,2,3
V = Variable, No Constant Value

Signature	Type	Definition	Value	Units
RDVKM	RD,M	1ST DERIVATIVE OF RUDDER (OR SPEEDBRAKE) POSITION FEEDBACK	V	--
SDVKM	S,M		V	--
RDVKIM	RD,M	DERIVATIVE OF DELTA P DEMOD OUTPUT RVKM	V	--
SDVKIM	S,M		V	--
RDVZM	RD,M	DERIVATIVE OF POSITION FEEDBACK DEMOD OUTPUT RVZM	V	--
SDVZM	S,M		V	--
RFMFLW	RD,M	HYDRAULIC FLOW INTO SERVO VALVE 2ND STAGE SPOOL	V	IN^3/SEC
SFMFLW	S,M		V	IN^3/SEC
RFMFT	RD,M	FLOW-FORCE INPUT FOR SERVO VALVE MOD PISTON	V	$\frac{IN^5}{SEC}$
SFMFT	S,M		V	$\frac{IN^5}{SEC}$
RDXSAM	RD,M	DERIVATIVE OF FLOW PER UNIT AREA INTO SERVO VALVE MOD PISTON RXSAM, SXSAM	V	--
SDXSAM	S,M		V	--

LEGEND:
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L = Left Panel
R = Right Panel
M = Multiple Use 1,2,3,4
N = Multiple Use 1,2,3
V = Variable, No Constant Value

Sheet 17

Signature	Type	Definition	Value	Units
RFN	RD,N	FORCE OUTPUT OF SERVO VALUE SECONDARY ACTUATOR	V	LB
SFN	S,N		V	LB
RBF	RD	TOTAL BERNOUILLI FORCE FEEDBACK TO INPUT OF POWER SPOOLS	V	LB
SBF	S		V	LB
RFTM	RD,M	FORCE FEEDBACK TO FLAPPER VALVE (1ST STAGE VALUE) IN SERVO SECONDARY ACTUATOR	V	IN-LB
SFTM	S,M		V	IN-LB
RFXM	RD,M	FLAPPER POSITION IN SERVO SECONDARY ACTUATOR	V	IN
SFXM	S,M		V	IN
RFXLMM	RD,M	FLAPPER VALVE LIMITER	V	IN
SFXLMM	S,M		V	IN
RFPM	RD,M	FLUID PRESSURE INTO SERVO SECONDARY ACTUATOR SECOND STAGE	V	PSI
SFPM	S,M		V	PSI

LEGEND: S = Speedbrake Only; RD = Rudder Only; X = Rudder and Speedbrake; L = Left Panel; R = Right Panel; M = Multiple Use 1,2,3,4; N = Multiple Use 1,2,3; V = Variable, No Constant Value

Sheet 18

Signature	Type	Definition	Value	Units
RHL	X	RUDDER HINGE LINE	--	--
QLN	RD,N	LOAD FLOW INTO HYDRAULIC MOTORS	V	IN^3/SEC
QSLN	S,N		V	IN^3/SEC
QLNGPM	RD,N	LOAD FLOW INTO HYDRAULIC MOTORS	V	GPM
QSLNGM	S,N		V	GPM
RILM	RD,M	LIMITED CURRENT INTO SECONDARY ACTUATOR TORQUE MOTORS	V	mA
SILM	S,M		V	mA
RINM	RD,M	INPUT COMMAND TO RUDDER/SPEEDBRAKE SUBSYSTEM	V	DEG
SINM	S,M		V	DEG
RLVM	RD,M	DERIVATIVE OF POSITION FEEDBACK RVDT OUTPUT	V	Vrms
SLVM	S,M		V	Vrms

LEGEND:
S = Speedbrake Only
RD = Rudder Only
X = Rudder and Speedbrake

L = Left Panel
R = Right Panel
M = Multiple Use 1,2,3,4
N = Multiple Use 1,2,3

V = Variable, No Constant Value

Signature	Type	Definition	Value	Units
RLVDTM	RD,M	DERIVATIVE OF RVDT OUTPUT	V	--
SLVDTM	S,M		V	--
RMINN	RD,N	FORCE INPUT TO MOTOR TO CAUSE ONE RADIAN OF ROTATION	V	IN-LB / RAD
SMINN	S,N		V	IN-LB / RAD
RMNRPM	RD,N	MOTOR SPEED	V	RPM
SMNRPM	S,N		V	RPM
RMSUMP	RD,P	MOTOR DYNAMICS FEEDBACK. 1, 3 AND 5 ARE TORQUE FEEDBACKS FROM PANELS WHERE 2,4 AND 6 ARE MOTOR DYNAMICS FEEDBACK	V	--
SMSUMP	S,P		V	--
RPVSN	RD,N	FEEDBACK CONSTANT OF SECONDARY ACTUATOR SERVO MOD PISTON	V	PSI
SPVSN	S,N		V	PSI
RQXSAM	RD,M	FLOW INTO SECONDARY ACTUATOR SERVO MOD PISTON	V	IN^3/SEC
SQXSAM	S,M		V	IN^3/SEC

LEGEND:
S = Speedbrake Only
RD = Rudder Only
X = Rudder and Speedbrake

L = Left Panel
R = Right Panel
M = Multiple Use 1,2,3,4
N = Multiple Use 1,2,3

V = Variable, No Constant Value

Sheet 20

Signature	Type	Definition	Value	Units
RSAPM	RD,M	INTERNAL FLOW IS SECONDARY ACTUATOR MOD PISTON	V	$\frac{IN^3}{SEC}$
SSAPM	S,M		V	$\frac{IN^3}{SEC}$
RSPM	RD,M	SECONDARY ACTUATOR MOD PISTON DYNAMICS FEEDBACK	V	--
SSPM	S,M		V	--
RSVPF	RD,M	FUNCTION SWITCH FOR POWER SPOOL INPUT RATE OF CHANGE	V	LB
SSVPF	S,M		V	LB
RSVIM	RD,M	POWER SPOOL FLUID VOLUME	V	IN^3
SSVIM	S,M		V	IN^3
RSVMIM	RD,M	POWER SPOOL OUTPUT FLOW	V	IN^3/SEC
SSVMIM	S,M		V	IN^3/SEC
RTM	RD,M	TORQUE INPUT TO SERVO SECONDARY ACTUATOR FLAPPER	V	IN-LB
STM	S,M		V	IN-LB

LEGEND: S = Speedbrake Only
RD = Rudder Only
X = Rudder and Speedbrake
L = Left Panel
R = Right Panel
M = Multiple Use 1,2,3,4
N = Multiple Use 1,2,3
V = Variable, No Constant Value

Sheet 21

Signature	Type	Definition	Value	Units
RTHETN	RD,N	MOTOR SHAFT POSITION	V	RADIANS
STHETN	S,N		V	RADIANS
RTFN	RD,N	TORQUE FEEDBACK TO MOTOR FROM PANELS	V	IN-LB
STFN	S,N		V	IN-LB
RTINM	RD,M	TORQUE INPUT TO SECONDARY ACTUATOR FLAPPER VALVE IN SERVO	V	IN-LB
STINM	S,M		V	IN-LB
RUDFB	RD	PANEL POSITION FEEDBACK TO RVDT'S	V	RADIANS
SBFB	S		V	RADIANS
RUDSUM	RD	OUTPUT OF SUMMER DIFFERENTIALS WITHOUT HYSTERESIS	V	RADIANS
SBSUM	S		V	RADIANS
RVINM	RD,M	VOLTAGE INPUT COMMAND TO ASA FROM MDM. LIMITED TO ±5.12 VOLTS DC.	V	VOLTS
SVINM	S,M		V	VOLTS

LEGEND:
S = Speedbrake Only
RD = Rudder Only
X = Rudder and Speedbrake
L = Left Panel
R = Right Panel
M = Multiple Use 1,2,3,4
N = Multiple Use 1,2,3
V = Variable, No Constant Value

Sheet 22

Signature	Type	Definition	Value	Units
RVKM	RD,M	DELTA P FEEDBACK CURRENT	V	mA
SVKM	S,M		V	mA
RVLM	RD,M	DELTA P PRESSURE TRANSDUCER FEEDBACK IN VOLTS	V	VOLTS
SVLM	S,M		V	VOLTS
RVZM	RD,M	POSITION FEEDBACK VOLTAGE	V	VOLTS
SVZM	S,M		V	VOLTS
RUD	RD	RADIAL POSITION MIDWAY DOWN MIXER GEAR TRAIN	V	RADIANS
SB	S		V	RADIANS
RXAM	RD,M	MOVEMENT ERROR OF SECONDARY ACTUATOR SERVO MOD PISTON	V	IN/SEC
SXAM	S,M		V	IN/SEC
RXSAM	RD,M	MOVEMENT OF SECONDARY ACTUATOR SERVO MOD PISTON	V	IN/SEC
SXSAM	S,M		V	IN/SEC

LEGEND:
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X = Rudder and Speedbrake
L = Left Panel
R = Right Panel
M = Multiple Use 1,2,3,4
N = Multiple Use 1,2,3
V = Variable, No Constant Value

Sheet 23

Signature	Type	Definition	Value	Units
RXM	RD,M	POWER SPOOL POSITION	V	IN
SXM	S,M		V	IN
RXSSM	RD,M	SERVO SECONDARY ACTUATOR 2ND STAGE SPOOL POSITION	V	IN
SXSSM	S,M		V	IN
STHDN	S,	SPEED OF INDIVIDUAL MOTORS	V	RADIANS/SEC
THDN	RD		V	RADIANS/SEC
RPS	X	SUPPLY PRESSURE IN SERVO SEC. ACTUATOR	2800	PSI

LEGEND: S = Speedbrake Only; RD = Rudder Only; X = Rudder and Speedbrake; L = Left Panel; R = Right Panel; M = Multiple Use 1,2,3,4; N = Multiple Use 1,2,3; V = Variable, No Constant Value

Signature	Type	Definition	Value	Units
TAUC	X	DYNAMIC LOAD DAMPING CONSTANT	0.1	SEC
TC		STATIC AND COULOMB FRICTION SWITCH IN MOTOR DYNAMICS	9.0	RAD/SEC
TDT		RVDT TIME CONSTANT	0.004	SEC
THDOTN	RD,N	ANGULAR POSITION OF INDIVIDUAL MOTORS	V	RADIANS
THDTSN	S,N		V	RADIANS
TLP	L	PANEL OUTPUT TORQUE	V	IN-LB
TRP	R		V	IN-LB
TPC	X	STATIC AND COULOMB FRICTION SWITCH IN LOAD DYNAMICS	0.0	DEG

LEGEND:
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X = Rudder and Speedbrake
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R = Right Panel
M = Multiple Use 1,2,3,4
N = Multiple Use 1,2,3
V = Variable, No Constant Value

Sheet 25

Signature	Type	Definition	Value	Units
VM	X	MOTOR FLUID VOLUME (INCLUDES FLUID LINES)	3.88	IN^3
VT	X	SPOOL AND NOZZLE FLUID VOLUME OF SERVO VALVE	0.0838	IN^3
VT2	X	MOD PISTON VOLUME OF SERVO VALVE	0.62	IN^3
WD	X	NATURAL FREQUENCY OF DEMODULATOR FILTER	314.0	$\frac{RAD}{SEC}$
XO	X	INITIAL FLAPPER DISPLACEMENT IN SERVO VALVE	0.00185	IN
XR	RD	POWER SPOOL POSITION	V	IN
XS	S		V	IN

LEGEND: S = Speedbrake Only; RD = Rudder Only; X = Rudder and Speedbrake; L = Left Panel; R = Right Panel; M = Multiple Use 1,2,3,4; N = Multiple Use 1,2,3; V = Variable, No Constant Value

Sheet 26

Signature	Type	Definition	Value	Units
XRD	RD	POWER SPOOL POSITION CHANGE (SPEED)	V	IN/SEC
XSD	S		V	IN/SEC
XRDDOT	RD	POWER SPOOL ACCELERATION	V	IN/SEC^2
XSDDOT	S		V	IN/SEC^2
XRDFB	RD	POWER SPOOL SPEED FEEDBACK FROM SPOOL DYNAMICS	V	IN/SEC
XSDFB	S		V	IN/SEC
XRDOT	RD	POWER SPOOL DYNAMICS SWITCH	V	--
XSDOT	S		V	--
XRL	RD	POWER SPOOL POSITION LIMITED TO ±XRM	V	IN
XSL	S		V	IN
XRM	RD	POWER SPOOL POSITION LIMIT	0.065	IN
XSM	S		0.065	IN

LEGEND: S = Speedbrake Only
RD = Rudder Only
X = Rudder and Speedbrake
L = Left Panel
R = Right Panel
M = Multiple Use 1,2,3,4
N = Multiple USE 1,2,3
V = Variable, No Constant Value

Sheet 27

Signature	Type	Definition	Value	Units
Y1	RD	POWER SPOOL LIMITING CONSTANT	1.0	LB
Z1	S		1.0	LB
Y2	RD	POWER SPOOL LIMITING CONSTANT	1.0	LB
Z2	S		1.0	LB

LEGEND: S = Speedbrake Only
RD = Rudder Only
X = Rudder and Speedbrake
L = Left Panel
R = Right Panel
M = Multiple Use 1,2,3,4
N = Multiple Use 1,2,3
V = Variable, No Constant Value

APPENDIX G

DISCUSSION OF USING HP9820 FOR PLOTTING

In the preparation of this report, the author has made extensive use of the Hewlett Packard HP9820 calculator and HP9866A Calculator plotter. This was accomplished to remove data from the IBM 360/75 printer plots and to clarify this information. The line printer can plot 10 characters per inch, but cannot plot between these characters whose plotted position is approximate. The HP9820 plots with such accuracy that the error is virtually undetectable and hence, a more accurate plot is produced from which information can be extracted. Figure G-1 (page G-3) is the basic listing of the HP9820 plotting program.

Another useful function of the HP9820 was to determine the average value of a number of points. This listing appears as figure G-2 (page G-7). Both programs have been loaded onto cassette magnetic tape for convenience.

```
0: REW ;SPC 4;PRT "    FILE 5","PLOTTING PROGRAM";0 TO
   X TO R19 TO Z;1 TO R24 [
1: SPC 1;ENT "X MAX",R1,"X MIN",R2 [
2: ENT "NUMBER POINTS",R27,"Y MAX",R5,"Y MIN",R6 [
3: FXD 0;PRT "TOTAL POINTS =",R27;FXD 08;PRT "+-+-+",
   "X MAX",R1,"X MIN",R2 [
4: PRT "Y MAX",R5,"Y MIN",R6;SPC 3 [
5: ENT "DELTA X TIC",R3;ENT "DELTA Y TIC",R7;ENT "X S
   TEP =",R18 [
6: ENT "NO DECIMALS X",R11;ENT "NO DECIMALS Y",R12 [
7: PRT "CHAR CODE","1 PLOT X","2 PLOT +" [
8: PRT "3 PLOT O","4 PLOT D","5 PLOT C","6 PLOT Y" [
9: PRT "7 PLOT U","8 PLOT .","9 PRINT LINE 54";SPC 1 [
10: (R1-R2)/R3 TO R9;(R5-R6)/R7 TO R10 [
11: (R1-R2)/10 TO A;(R5-R6)/10 TO B;0 TO C TO R0 [
12: 1+C TO C;JMP CR3>A [
13: 1+R0 TO R0;JMP R0R7>B [
14: R2-CR3 TO R4;R6-R0R7 TO R8 [
15: SCL R4,R1,R8,R5 [
16: AXE R2,R6,R3,R7;.0032(R1-R4) TO R0;0 TO B;FXD R11 [
17: LTR R2+BR3-2R0,R8,212;PLT R2+BR3;JMP (1+B TO B)>R9 [
18: .0032(R5-R8) TO A;0 TO B;FXD R12 [
19: LTR R4,R6+BR7-4A,211;PLT R6+BR7;JMP (1+B TO B)>R10 [
20: SPC 2;PRT "FOR COMPLETE","LIST OF X,Y","DATA, DATA
    =1";SPC 1;ENT "DATA?",R23 [
21: ENT "CHAR CODE",C;0 TO B TO R14;IF C=9;GTO 51 [
22: ENT "1 TO CONNECT PTS",B;PEN  [
23: ENT "PRINT DECIMALS",R13;PRT "DATA" [
```

```
24:  CFG 13;X+R19R18+R2R24 TO X;IF (Z+1 TO Z)>R27;GTO 51 [
25:  0 TO R24;IF R23=0;JMP 2 [
26:  FXD 0;PRT "NO. ",Z;FXD R13;PRT "X=",X;ENT "Y=",Y;P
     RT "Y=",Y;SPC 1;1 TO R19;JMP 2 [
27:  ENT "Y=",Y;1 TO R19;FXD 0;PRT Z;FXD R13 [
28:  IF R14=0;JMP 3 [
29:  IF B=0;JMP 2 [
30:  PLT R15,R16 [
31:  PLT X,Y;PEN  [
32:  LTR X-R0,Y-A,111 [
33:  IF C>1;JMP 2 [
34:  PLT "X";GTO 49 [
35:  IF C>2;JMP 2 [
36:  PLT "+";GTO 49 [
37:  IF C>3;JMP 2 [
38:  PLT "O";GTO 49 [
39:  IF C>4;JMP 2 [
40:  PLT "D";GTO 49 [
41:  IF C>5;JMP 2 [
42:  PLT "C";GTO 49 [
43:  IF C>6;JMP 2 [
44:  PLT "Y";GTO 49 [
45:  IF C>7;JMP 2 [
46:  PLT "U" [
47:  IF C>8;GTO 54 [
48:  PLT " " [
49:  PEN ;LTR X,Y;PEN ;IF Z+1=R27;DSP "LAST POINT"," ",
     "LAST POINT"," " [
```

```
50: R14+1 TO R14;X TO R15;Y TO R16;GTO 24 [
51: SPC 3;DSP "CONT","CONT","    INUE","CONTINUE";ENT
    "ERRORS?",C;IF C # 1;GTO 66 [
52: ENT "ERROR X LOCATION",R25,"ERROR Y LOCATION",R26;
    LTR R25,R26,211 [
53: PLT "PLOT ERROR--";JMP -2 [
54: LTR R2+.8(R1-R2),R6-.02(R5-R6),211;PLT "TIME(SEC)-
    -*" [
55: LTR R2-.01(R1-R2),R6+.8(R5-R6),212;PLT "RESPONSE--
    --*" [
56: ENT "START   LABEL X",A,"START LABEL Y",B [
57: LTR A,B,211;PLT "10 DEG/SEC RUDDER COMMAND" [
58: LTR A,B-.03(R5-R6),211;PLT "X IS" [
59: LTR A,B-.06(R5-R6);PLT "+ IS" [
60: LTR A,B-.09(R5-R6);PLT "LOCKHEED ELECTRONICS CO" [
61: LTR A,B-.12(R5-R6);PLT "HENRY DUKE" [
62: PRT "PRINT DATE =1";SPC 2;ENT "DATE ?",R28;FXD 0;I
    F R28=0;GTO 68 [
63: ENT "MONTH",R29,"DAY",R30,"YEAR",R31;R5-R6 TO R33;LT
    R A,B-.15R33;PLT R29 [
64: .0096(R1-R2) TO R32;LTR A+2R32,B-.15R33;PLT "-";LTR
    A+3R32,B-.15R33 [
65: PLT R30;LTR A+5R32,B-.15R33;PLT "-";LTR A+6R32,B-.
    15R33;PLT R31 [
66: PRT "END       =0","NEW PLOT =1","LABEL    =2";SPC
    2 [
67: ENT "DECISION?",R22;IF R22=0;PRT "DECISION END";GT
    O 74 [
```

```
68: IF R22=1;PRT "NEW PLOT";GTO 71 [
69: IF R22=2;PRT "LABEL";GTO 54 [
70: IF R22>2;PRT "DECISION ERROR";GTO 67 [
71: ENT "NUMBER POINTS",R27 [
72: 0 TO X TO R19 TO Z;1 TO R24;ENT "X STEP=",R18 [
73: .0032(R1-R4) TO R0;0 TO B;FXD R11;.0032(R5-R8) TO A;0 TO B
    ;FXD R12;GTO 21 [
74: PRT "+-+-+-+-+-+-+-+";SPC 8 [

75: END [
```

```
0:  REW ;PRT "-+-+-+-+-+-+-+-+-","PROGRAM FOR","CONTINUO
    US","AVERAGE" [
1:  PRT "----------------";SPC 2 [
2:  0 TO R0;0 TO X;0 TO Y;ENT "DECIMALS",B;FXD B [
3:  R0+1 TO R0 [
4:  ENT "VALUE",RR0;IF FLG 13;JMP 3 [
5:  RR0+Y TO Y [
6:  X+1 TO X;JMP -3 [
7:  Y/X TO Z;PRT "NO POINTS=",X,"AVERAGE=",Z [
8:  PRT "------END--------";CFG 13 [
9:  PRT "NEW PLOT=1","CONTINUE=2","END=3";ENT "DECISIO
    N?",A [
10: IF A=1;JMP -8 [
11: IF A=2;JMP -8 [
12: PRT "------STOP------";SPC 6 [
13: END  [
```

APPENDIX H

DEADSPACE PLOTS

APPENDIX H FIGURES

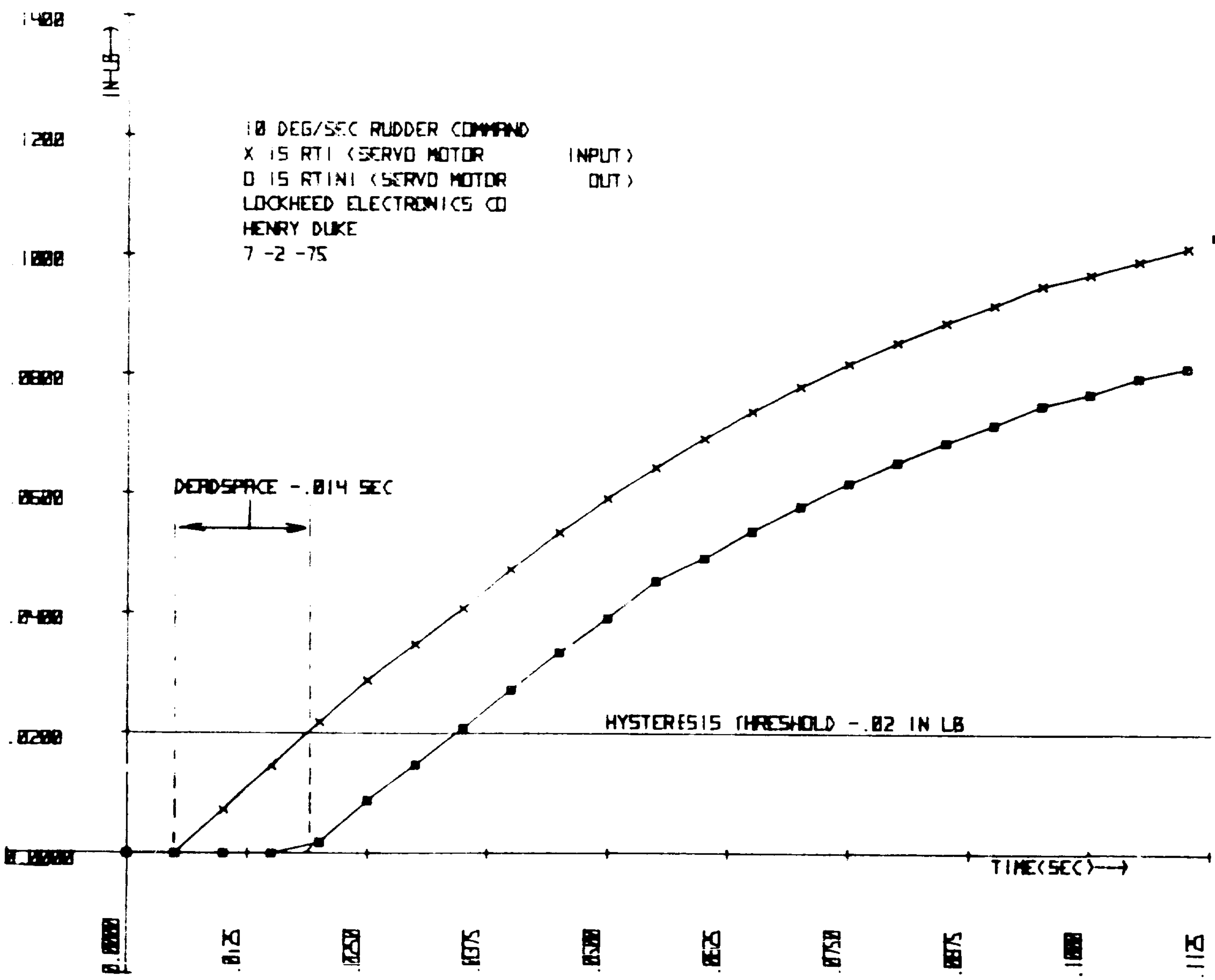

Figure H-1. – 10-deg/sec Rudder servo valve hysteresis.

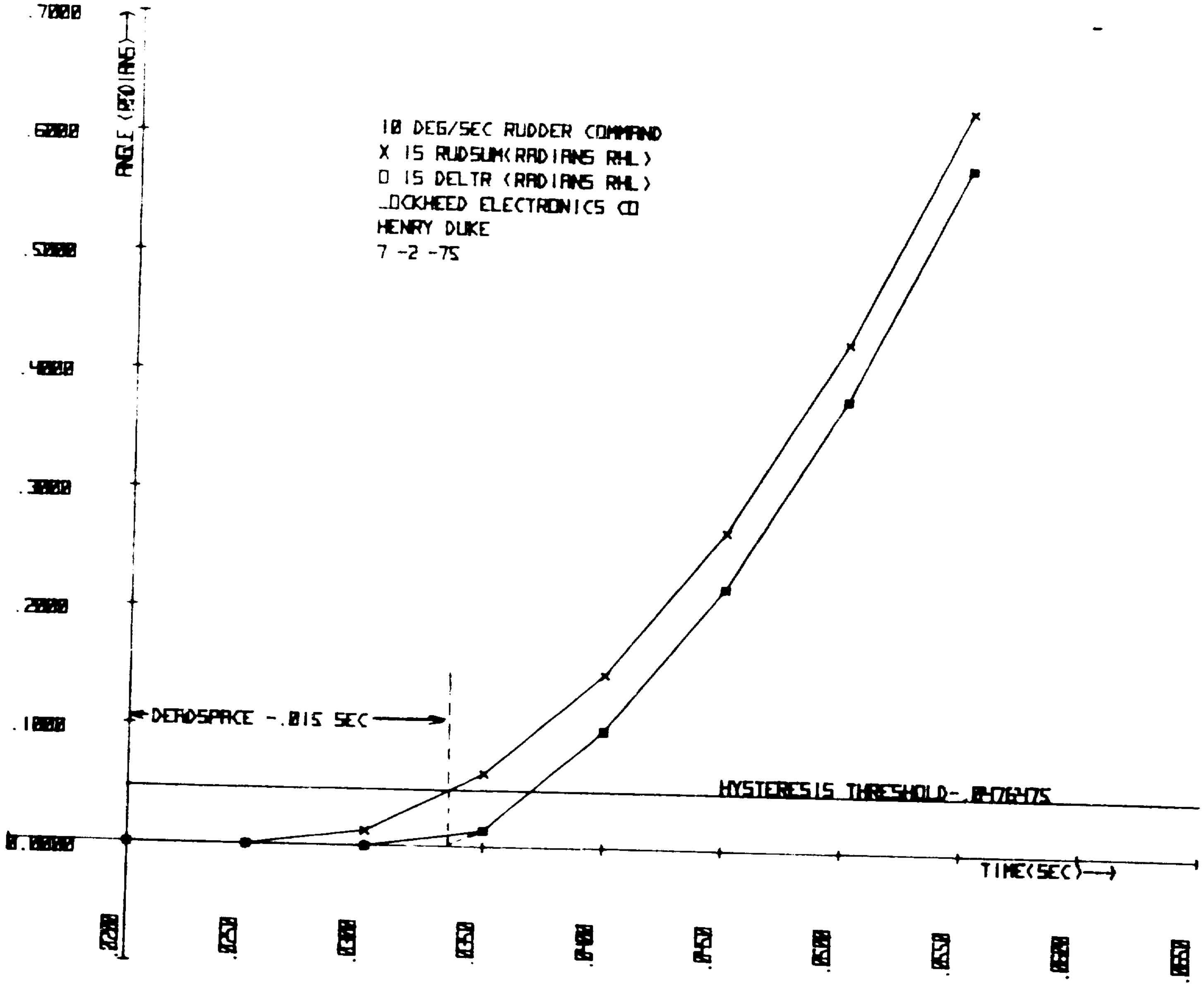

Figure H-2. – 10-deg/sec Rudder summer valve hysteresis.

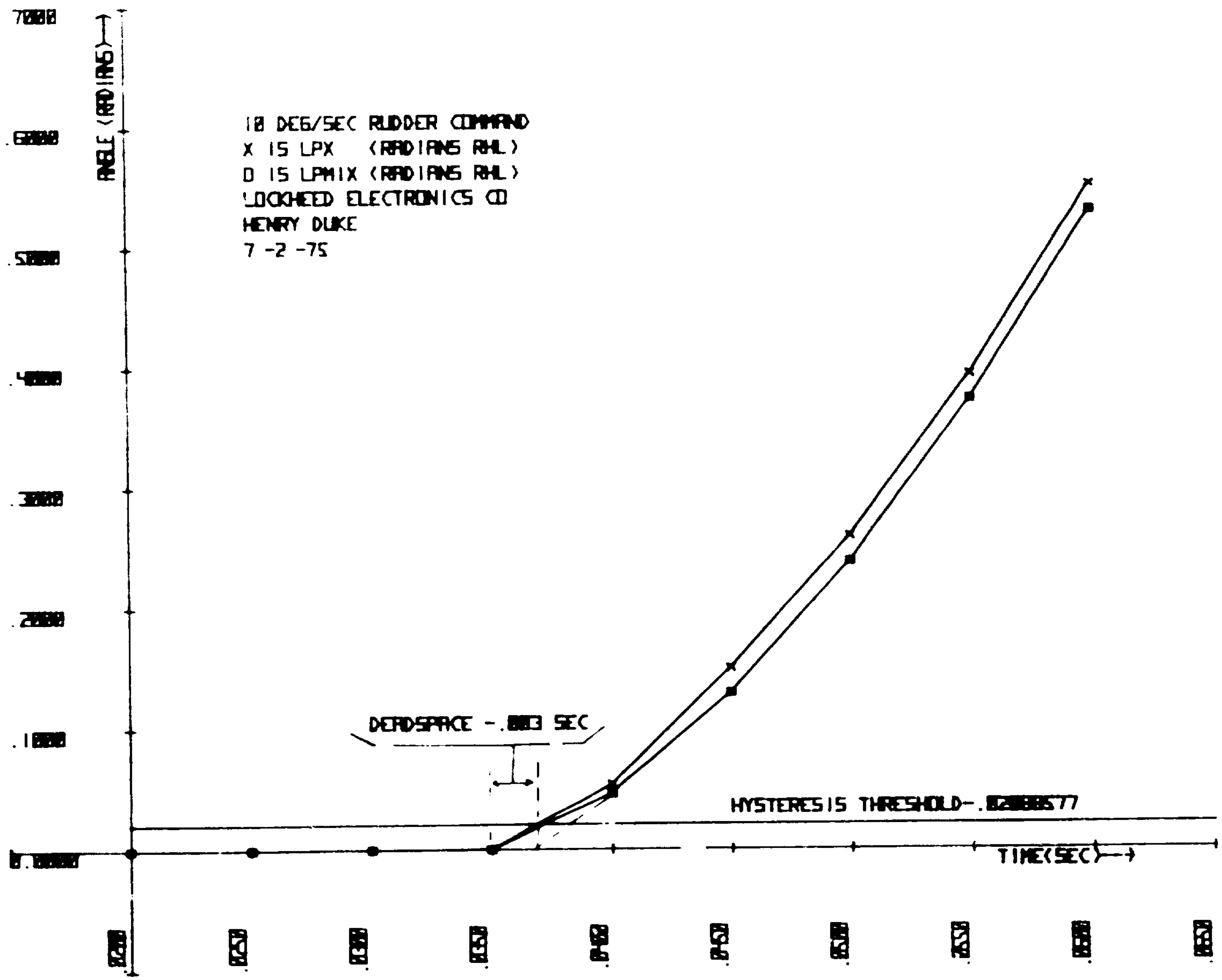

Figure H-3. — 10-deg/sec Rudder mixer valve hysteresis.

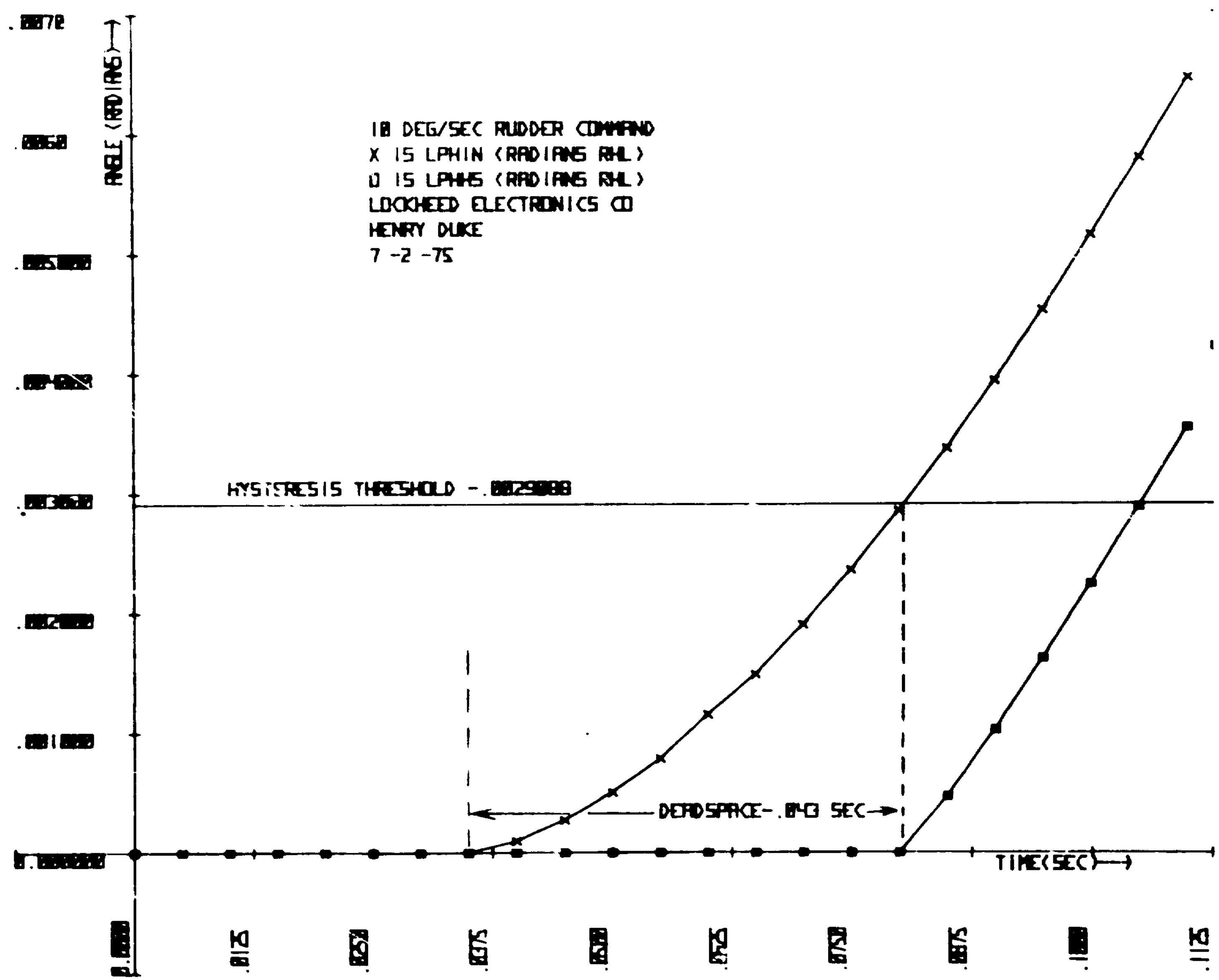

Figure H-4. — 10-deg/sec Rudder PDU valve hysteresis.

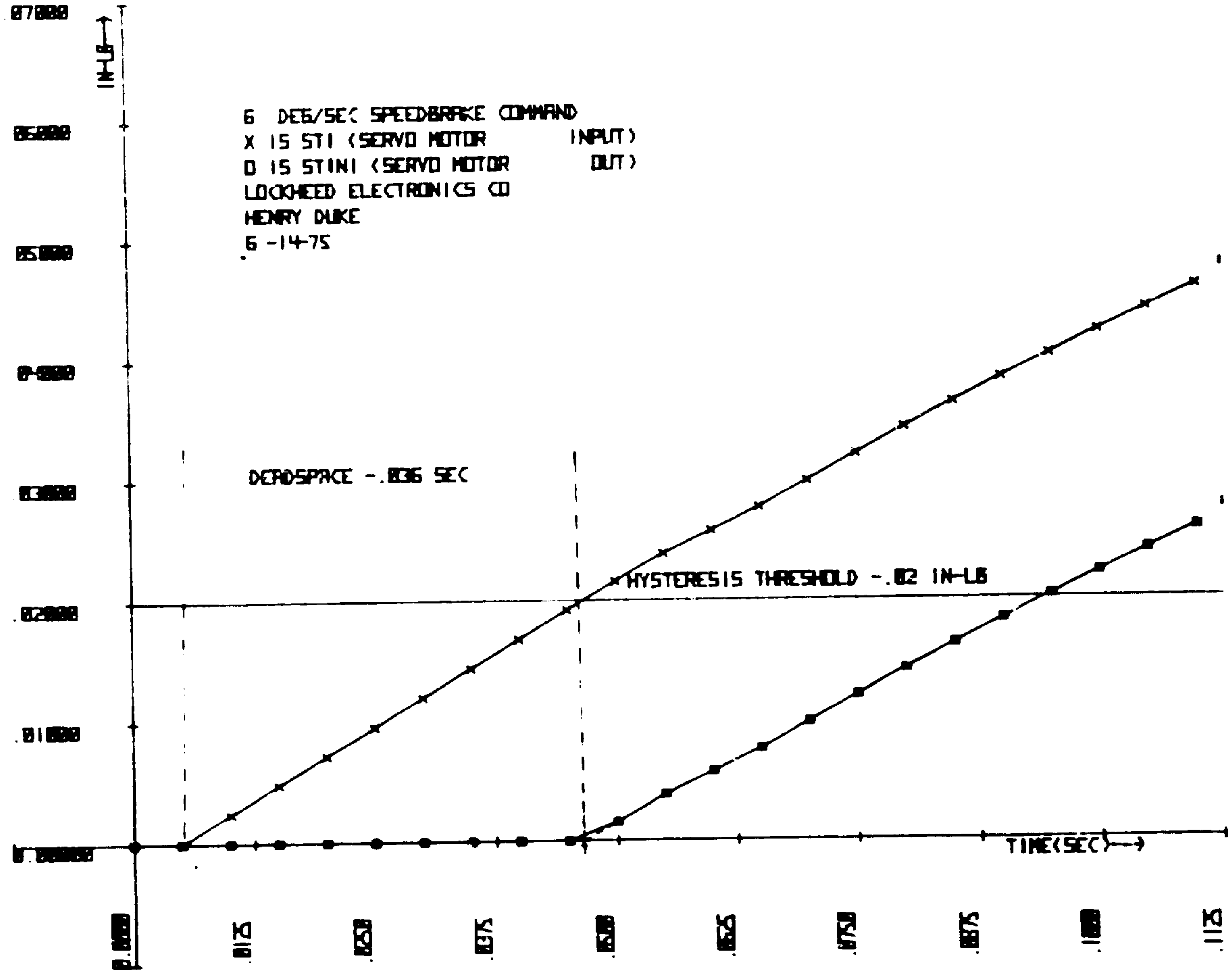

Figure H-5. – 6-deg/sec Speedbrake servo valve hysteresis.

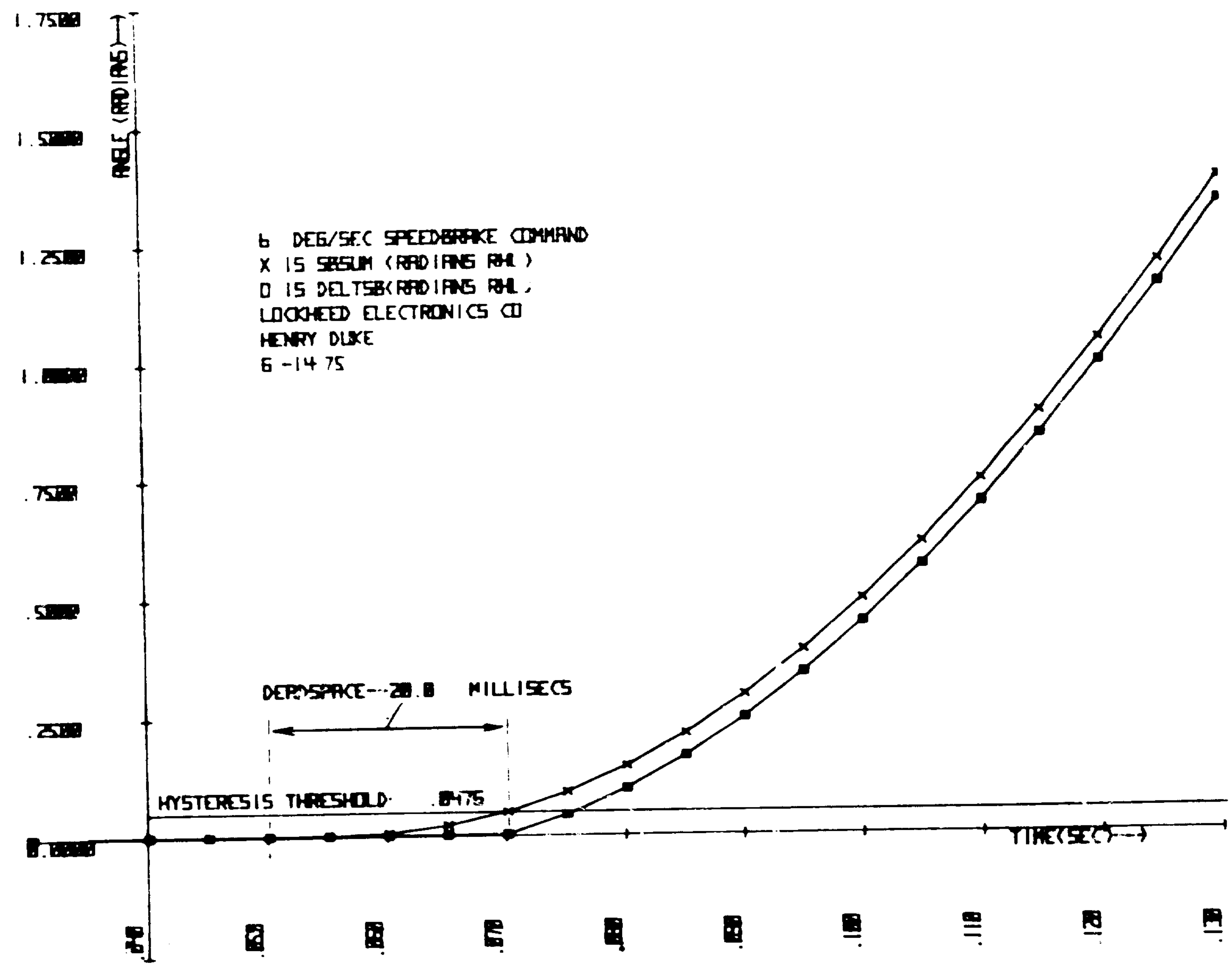

Figure H-6. - 6-deg/sec Speedbrake summer valve hysteresis.

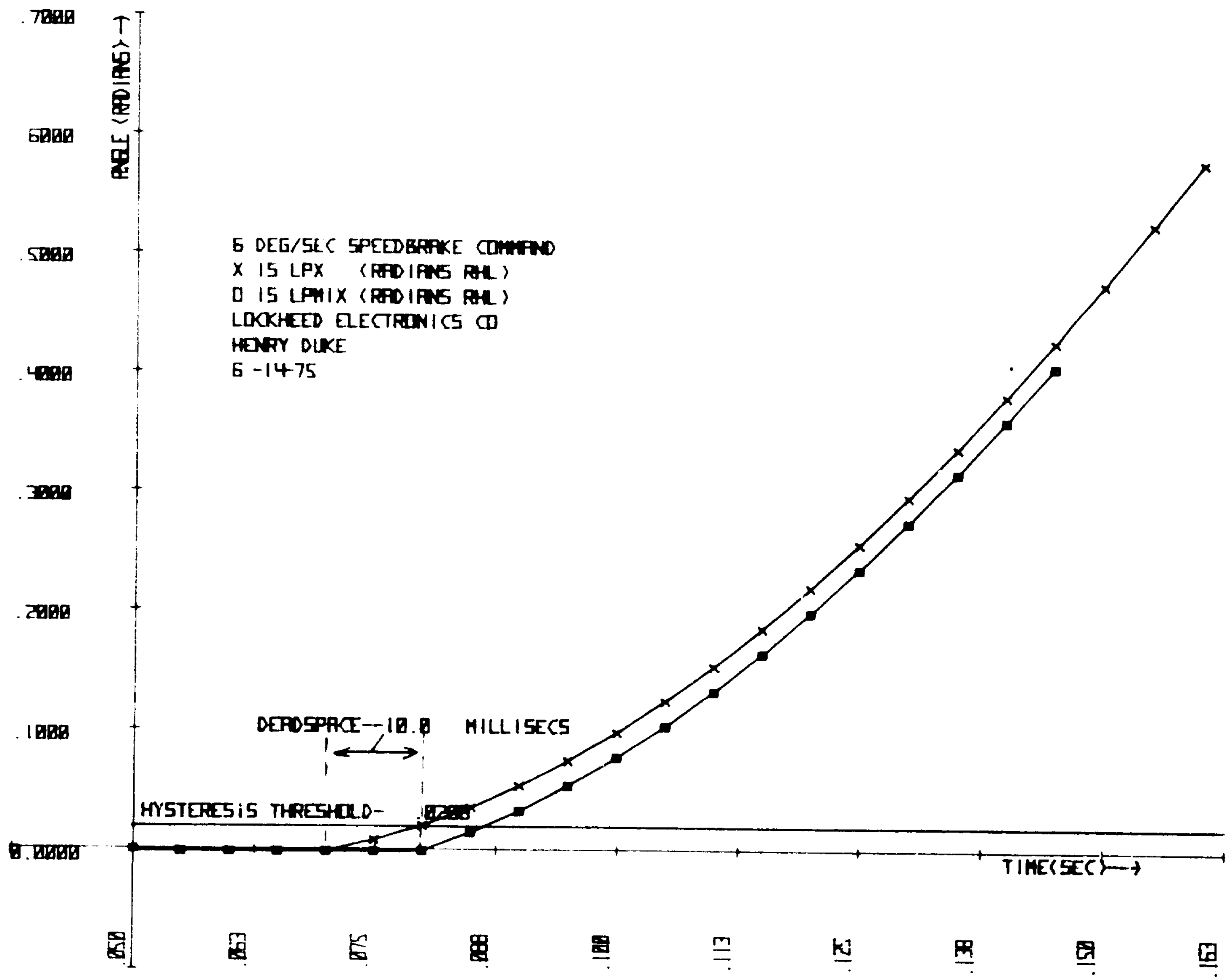

Figure H-7. – 6-deg/sec Speedbrake mixer valve hysteresis.

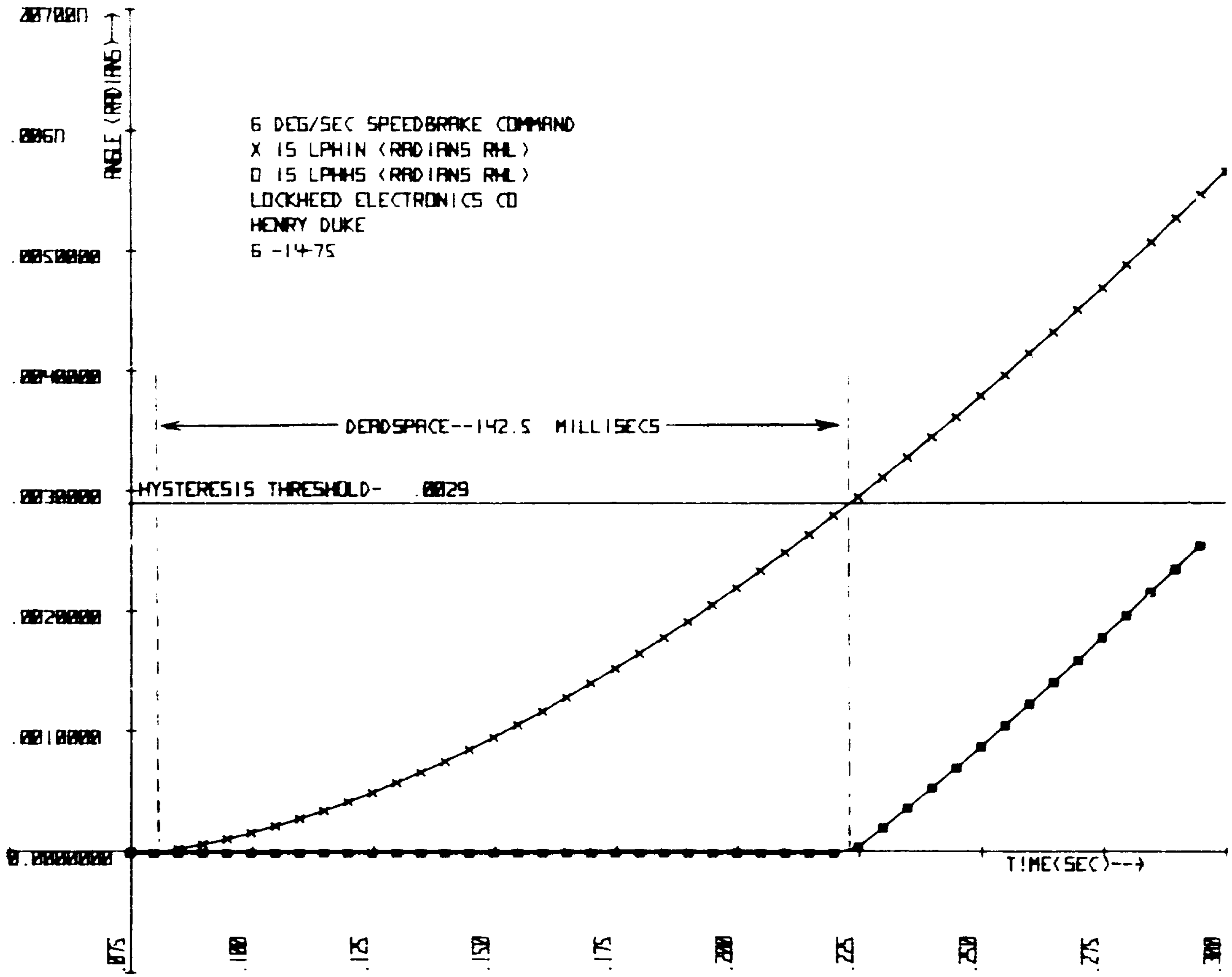

Figure H-8. — 6-deg/sec Speedbrake PDU valve hysteresis.

APPENDIX I

DISCUSSION OF INPUT COMMANDS

APPENDIX I FIGURES

The input command from the pilot will probably be given as a quick transition from one state to the next in a very short period of time. This is best represented by a step command. This analog step will be sampled by the MDM (MDM #1 as shown in figure I-1) at a 40-millisecond refresh rate and addressed through the IOP to the FCS computer. The computer will then determine the necessary commands to the subsystem to respond to the pilot's requested command.

Since the computer, through software, sets up both position and rate limits, it will determine the magnitude of each step of the stairstep commanded to the subsystem. Position commands are set at 27.1 degrees (Rudder) and 49.3 degrees (Speedbrake) with rate limits presently set at 12.1 degrees/second (Rudder), 6.1 degrees/second (Speedbrake opening), and 10.85 degrees/second (Speedbrake closing).

A digital command is then sent through the IOP to MDM #2 where it is converted to the stairstep analog command which is addressed into the Rudder/Speedbrake subsystem through the ASA.

The value shown for the stairstep voltage will vary from a 10 mV minimum to a maximum set by FCS computer rate limiting. The computer furnishes 10 bits to the MDM of which the highest represents the sign. This leaves 2^9 bits or 512 possible absolute combinations. The weight of each combination is 10 mV, therefore the maximum voltage output will be 5.12 volts. The computer has set a position limit of 27.1 degrees for the Rudder and 49.3 degrees for the Speedbrake, both of which are defined as 5.00 volts (not 5.12 volts). Therefore the actual maximum binary count is 500, not 512.

The refresh rate of the signal applied to the MDM is 40 ms, therefore the time required for each step is 40 ms as set by the FCS computer.

At rate limiting, the slew rate required for each panel is:

$$\text{Rudder} = \frac{(5.0\ \text{volts})(12.1\ \text{degrees})}{(27.1\ \text{degrees})(1\ \text{second})} = 2.232\ \frac{\text{volts}}{\text{second}}$$

$$\text{Speedbrake (opening)} = \frac{(5.0\ \text{volts})(6.1\ \text{degrees})}{(49.3\ \text{degrees})(1\ \text{second})} = 0.619\ \frac{\text{volts}}{\text{second}}$$

$$\text{Speedbrake (closing)} = \frac{(5.0\ \text{volts})(10.85\ \text{degrees})}{(49.3\ \text{degrees})(1\ \text{second})} = 1.100\ \frac{\text{volts}}{\text{second}}$$

The maximum voltage* step in 40 ms is therefore:

$$\text{Rudder} = \frac{(2.232\ \text{volts})(0.04\ \text{seconds})}{(1\ \text{second})} \cong 0.09\ \text{volts}$$

$$\text{Speedbrake (opening)} = \frac{(0.619\ \text{volts})(0.04\ \text{seconds})}{(1\ \text{second})} \cong 0.02\ \text{volts}$$

$$\text{Speedbrake (closing)} = \frac{(1.100\ \text{volts})(0.04\ \text{second})}{(1\ \text{second})} \cong 0.04\ \text{volts}$$

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*Rounded to closest multiple of 10 mV.

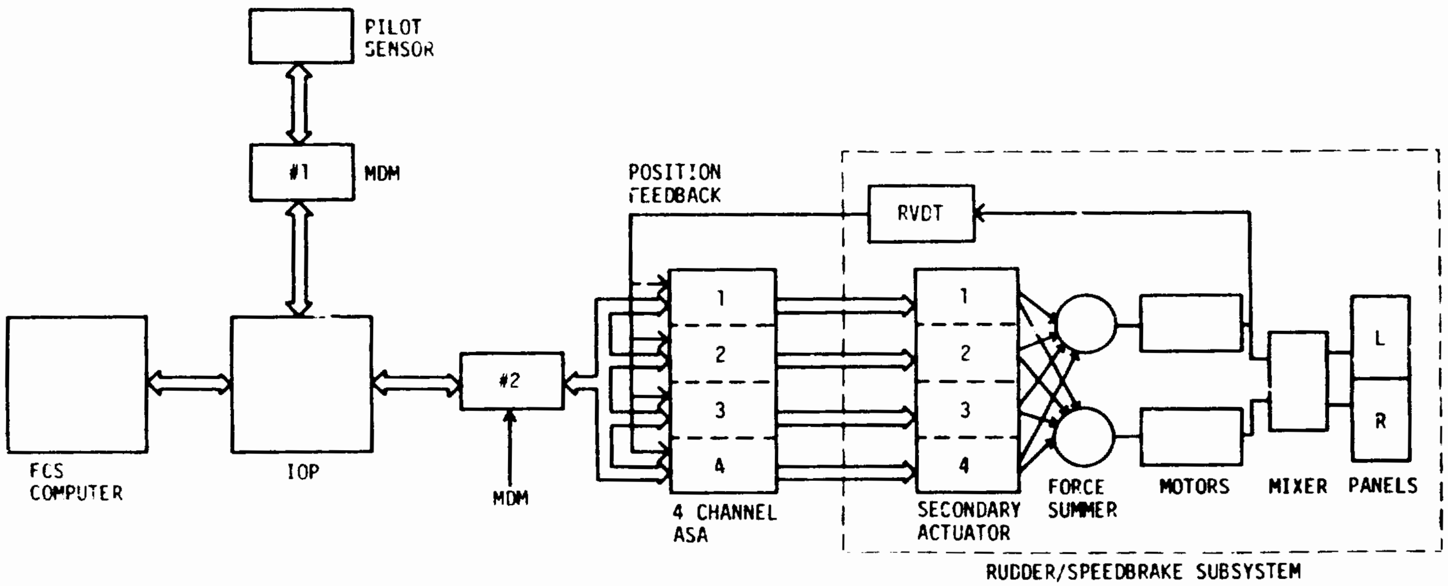

Figure I-1. – Rudder/Speedbrake command channels.

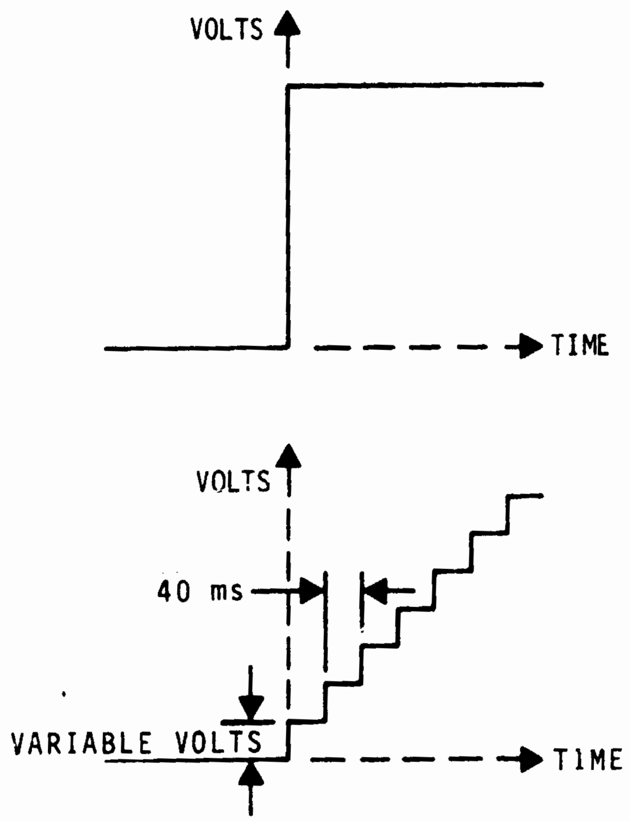

Figure I-2. – Stairstep for Rudder/Speedbrake input.