11176-H394-R0-00

PROJECT TECHNICAL REPORT
TASK E-72B

LUMINARY 1B DAP PREFLIGHT PERFORMANCE EVALUATION

NAS 9-8166 — 13 November 1969

Prepared for
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
MANNED SPACECRAFT CENTER
HOUSTON, TEXAS

Prepared by
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Control Systems Analysis Section

TRW SYSTEMS GROUP

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Task E-72B

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1. INTRODUCTION

This report presents the results of ten simulation runs comprising the LUMINARY 1B Digital Autopilot Software Verification and Performance Evaluation Testing for Mission H1. The LUMINARY 1B testing was oriented toward investigation and evaluation of the functions actually impacted by the DAP modifications from LUMINARY 1A. The runs made consider the following sequences or cases:

1. Nominal descent (H1-1.0).
2. Off-nominal descent (H1-1.2), RCS quad misalignments and undetected jet failure.
3. Descent with large lateral redesignation (H1-1.3).
4. Use of ΔRLS method prior to ignition (H1-1.4).
5. Use of ΔRLS method 3 minutes after PDI (H1-1.5).
6. DPS/APS abort in P64 (H1-3.0).
7. APS abort in P64 (H1-3.1).
8. Undetected failure of DPS gimbals (H1-1.6A, H1-1.6B, and H1-1.6D).

The reported tests were obtained from the all digital MSC Block II AGC bit-by-bit Simulation and the LUMINARY 1B, Rev. 116 flight program. The initialization used in implementing these descent simulations places the spacecraft in a yaw attitude prior to DPS which requires the use of the automatic windows-up maneuver in P63. The maneuver has subsequently been removed from the flight plan of Apollo 12. Its removal from the descent sequence was not finalized at the time the Descent Run initialization was set up.

It was observed during the course of the testing that the mass properties being used in the simulator environments are consistent with the latest issue of Section 6 of the GSOP. This revision of the GSOP was dated November 1968. Consequently, the spacecraft mass properties in the simulator are different from those defined in the Spacecraft Operational Data Book for Apollo 12. Inertias and c.g. locations in the simulator differ slightly from those given in the S.O.D.B. To prevent mass mismatching between the LGC and the simulator environments, the DAP erasable load was adjusted to correlate with the simulator mass data. The effect of the mass adjustment did not substantially alter the DAP performance.

Section 2 of this report presents a condensed summary of significant results for each run. Section 3 contains the detailed run analyses, including various plots. General conclusions are drawn in Section 4.

2. SUMMARY OF RESULTS

This section summarizes the significant results of the ten sumulations made for the LUMINARY 1B testing. Refer to Tables 1, 3, and 5 for lists of key variables, their magnitudes, and times of occurrence. Detailed results of the analyses are presented in Section 3.

2.1 Nominal Descent, Run H1-1.0

The nominal descent test case was initiated with the spacecraft in satisfactory descent orbit. Both the DPS GTS and RCS functioned as designed and as expected. Fuel slosh effects appeared as with previous testing but caused no stability problems. Lunar Descent programs P63, P64, and P65 worked well with the mission H1 targeting. The incorporation of 0.3 degree deadband in P64 and P65 reduced the attitude and rate error oscillation amplitudes substantially.

2.2 Off-Nominal Descent, Run H1-1.2

The off-nominal descent was essentially the same as the nominal descent case with RCS quad misalignments and undetected failure of one of the jets used during automatic pitchover in P64. The RCS 3σ quad misalignments did not alter the RCS control effectiveness enough to substantially affect the vehicle response during descent. One of the pitchover jets was failed just prior to entrance to P64. This resulted in a pitchover which required more time to complete and included additional roll transients due to the undetected jet failure. No adverse stability effect was noted.

2.3 Landing Sequence with RHC Lateral Redesignations, Run H1-1.3

Three single click lateral redesignations were entered via the ACA (Attitude Controller Assembly) late in P64 (TREDES = 40 sec.) The redesignations were executed at 4 second intervals. Guidance issued large commands in conjunction with these redesignation. These large guidance commands produced rather large transients which the DAP damped quickly with essentially no overshoot. Fuel slosh effects were not excessively excited by the transients resulting from redesignations.

2.4 Descent with ΔRLS Redesignation Prior to Ignition, Run H1-1.4

The ΔRLS method via NOUN 69 was used to redesignate the landing site position during P63 and prior to ignition. A 10,000 ft downrange redesignation was incorporated and the proper adjustment in time of ignition was made in the ignition algorithm. The delay in ignition time resulted in a touchdown point 10,069 feet downrange from the original landing site.

2.5 Landing Sequence with ΔRLS Redesignation After PDI, H1-1.5

The ΔRLS method via NOUN 69 was used to redesignate the landing site approximately 3 minutes after PDI. A 10,000 ft. downrange redesignation was incorporated and resulted in a 10,050 ft downrange change in the actual landing position relative to results obtained for the nominal case.

2.6 DPS/APS Abort from Powered Descent While in P64, Run H1-3.0

An abort from powered descent late in P64 using the DPS was initiated. Upon exhaustion of DPS fuel, the abort was continued using the APS. Proper deadband sequencing from P64 to P70 was verified. Spacecraft response and DAP performance were nominal throughout the abort (P70, P71). Staging and fire-in-the-hole (FITH) transients were controlled and damped quickly by the DAP.

2.7 APS Abort from Powered Descent While in P64, Run H1-3.1

This test case was essentially the same as Run H1-3.0 except the entire abort sequence was performed using the APS. Proper deadband sequencing was verified for the P64 to P71 transition. DAP performance and spacecraft response were nominal for the P71 burn.

2.8 Descent with Undetected Failure of DPS Gimbals, Runs H1-1.6A, H1-1.6B, and H1-1.6D

These three runs were nominal descent runs with failure of the DPS gimbals at 212 seconds after ignition. H1-1.6A included gimbal failure with no initial mistrims. H1-1.6B and H1-1.6D included 1 degree mistrims in pitch and roll respectively at the time of failure. The results of these cases are summarized with the following values of RCS duty cycle.

Run	RCS Duty Cycle
H1-1.0 (nominal descent)	9.15%
H1-1.6A	14.2%
H1-1.6B	67.1%
H1-1.6D	65.0%

Spacecraft response for theses cases was very smooth and fuel slosh effects were substantially reduced in amplitude.

3. DETAILED TEST RESULTS

This section presents the detailed results of the analyses made on the six simulations. The following subheadings are considered for each of the six runs: 1) Test Description, 2) Test Objective, 3) Initialization Data, 4) Timeline, and 5) Results. The nomenclature presented below is incorporated in the plots and results discussion.

NOMENCLATURE

Variable	Description
PERROR, QERROR, RERROR	Yaw, pitch, and roll angular attitude errors about spacecraft body axes. (deg)
UERROR, VERROR	Angular attitude errors around the U' and V' control axes. (deg)
OMEGAX, OMEGAY, OMEGAZ	Yaw, pitch, and roll angular spacecraft body rates (actual) as simulated in the AGC Simulation Environments Section. (deg/sec)
OMEGAP, OMEGAQ, OMEGAR	Yaw, pitch, and roll LGC estimated angular rates about spacecraft body axes. (deg/sec)
OMEGAU, OMEGAV	LGC estimated angular rate errors around the U' and V' control axes. (deg/sec)
AOSQ, AOSR	Offset angular acceleration estimates about the Q and R spacecraft axes. (angular accelerations resulting from disturbance torques) (deg/sec^2)
JPY, JPZ	DPS Gimbal angles about Y and Z axes. (deg)
THRUST MAG	Magnitude of DPS or APS output thrust. (lbs)

3.1 NOMINAL DESCENT, RUN H1-1.0

Test Description

Nominal Automatic Landing including the nominal terrain model and landing radar model - trajectory shaped by current aim targets. Nominal DPS initial thrust alignment. Descent Orbit Injection (DOI) has been completed and LM is in proper descent orbit at the beginning of the test.

Test Objective

Evaluate the DAP performance in a nominal descent sequence with current guidance requirements. Observe DAP operation in the descent programs P63, P64, and P65 with particular emphasis on transition periods between successive programs.

Initialization Data

The nominal descent test case begins from a nominal descent orbit with the following parameter values just before ignition:

Initial Vehicle Weight and Configuration:

LM-alone, descent and ascent stages
Total Weight = 33125.061 lbs

Center of Gravity Location:

$$\begin{bmatrix} CGX \\ CGY \\ CGZ \end{bmatrix} = \begin{bmatrix} 187.068 \\ 0.086 \\ 0.721 \end{bmatrix} \text{ inches, (LM-coordinates)}$$

Inertia Matrix:

$$[I] = \begin{bmatrix} I_{xx} & I_{xy} & I_{xz} \\ I_{yx} & I_{yy} & I_{yz} \\ I_{zx} & I_{zy} & I_{zz} \end{bmatrix} = \begin{bmatrix} 23028.303 & -94.058 & -616.228 \\ -94.058 & 25026.685 & -272.780 \\ -616.228 & -272.780 & 25054.128 \end{bmatrix} \text{ slug-ft}^2$$

Initial Attitude and Rate Errors:

$$\begin{bmatrix} PERROR \\ QERROR \\ RERROR \end{bmatrix} = \begin{bmatrix} +0.75 \\ -0.14 \\ -1.3 \end{bmatrix} \text{ deg}$$

$$\begin{bmatrix} OMEGAP \\ OMEGAQ \\ OMEGAR \end{bmatrix} = \begin{bmatrix} 0.006 \\ 0.007 \\ 0.002 \end{bmatrix} \text{ deg/sec}$$

DPS Gimbal Angles:

1) At beginning of simulation

$$\begin{bmatrix} JPY \\ JPZ \end{bmatrix} = \begin{bmatrix} 1.247 \\ -0.151 \end{bmatrix} \text{deg}$$

2) Theoretical trim angles for initial c.g. location (no thrust/c.g. offset)

$$\begin{bmatrix} JPY \\ JPZ \end{bmatrix} = \begin{bmatrix} 1.247 \\ -0.151 \end{bmatrix} \text{deg}$$

Simulation Options Exercised:

1) Compliance effects of DPS mounting structure
2) Fuel Slosh effects (Old linear slosh model)
3) RCS jet deflectors

Fuel Loadings:

DPS fuel loading = 17,588 lbs (100%)
APS fuel loading = 5,078 lbs (100%)

Ullage Used:

1) Type = two jet (6, 14)
2) Duration = 8 sec

Timeline

The following is a list of the major events and their times of occurence.

	Time-Seconds	Event
1)	205.0575	Ullage Initiated
2)	212.5605	DPS Engine Ignition Command
3)	213.0565	Ullage Completed
4)	717.0752	Enter Visibility Phase Program, P64
5)	861.2918	Enter Automatic Terminal Landing Phase Program, P65
6)	890.5565	LM Stop Button
7)	891.1395	DPS Engine Off
8)	891.3566	Touchdown Confirmed

The total time between ignition and lunar touchdown was 678.7961 sec or 11.31 minutes. The plots presented in Figures 1 thru 14 consider only the time interval from ullage to lunar touchdown.

Results

Figures 1 thru 16 are plots of the various LGC and Environment parameters pertinent to this test case. Table 1 indicates the magnitudes and times of occurence of certain key variables. Table 2 presents a summary of the RCS activity. Data for Figures 1 thru 14 was obtained every fifth DAP cycle or 0.5 sec while data for Figures 15 and 16 were obtained every DAP cycle.

The LUMINARY 1B DAP is essentially the same as the LUMINARY 1A DAP. The only significant change in the area of powered descent is the change from a 1.0 degree deadband to a 0.3 degree deadband for programs P64, P65, P66, and P67. The deadband for P63 is still set at 1.0 degree.

The response for Run H1-1.0 during the Braking Phase Program P63 is very similar to that of the LUMINARY 1A simulation runs. (Reference 2) The start-up transients were damped quickly and attitude errors were held with the 1.0 degree deadband quite easily. Noticeable slosh oscillations started building up about 200 seconds into the burn for the roll axis and about 300 seconds into the burn for the pitch axis. The slosh oscillations are rather small at first and have a frequency of approximately 0.5 Hz. Soon the GTS-slosh-RCS combination begins to interact and the amplitude of the oscillations begin to grow. The peaks rates for the roll axis reach a peak-to-peak amplitude of 3.43 deg/sec and the pitch rate peaks out at an amplitude of 3.8 deg/sec. The higher frequency slosh oscillations are superimposed on a low frequency oscillation of approximately 0.15 Hz. These same characteristics were observed in the Apollo 11 preflight simulations and an analysis of this instability was reported in Reference 3. It should be pointed out that the exact behavior of this phenomenon is very sensitive to the slosh model; however, results of several simulations predict the same general characteristics.

The Visibility Phase program, P64, was entered 504.5 seconds after ignition. The pitchover maneuver started approximately one second after the start of P64. The commanded pitchover angle was 3[illegible] degrees and the peak angular rate about the pitch axis during this maneuver was 11.5 deg/sec. Figures 15 and 16 are expanded plots of pitch and roll rates respectively during the pitchover maneuver. It can be seen that there is very little overshoot in the pitch axis during the maneuver. The oscillations seen in these figures are caused by slosh. It is interesting to note that the estimated rates, OMEGAQ and OMEGAR, lag the environment or actual rates, OMEGAY and OMEGAZ, by almost 90 degrees phase angle at the slosh frequency. This is one of the contributors to the slosh instability which was mentioned earlier. The rate amplitudes dropped significantly in P64 and P65 after the deadband was changed to 0.3 degree. The rate errors about the U' and V' control axes reached steady-state peak-to-peak values of 1.0 deg/sec and the amplitudes of the attitude errors were about 0.8 degree peak-to-peak.

The change to the 0.3 degree deadband caused a significant increase in the number of RCS jet firings in P64 and P65. The RCS propellant consumption during P64 and P65, exclusive of the pitchover maneuver, was about 13.7 pounds compared to 7.3 pounds for the LUMINARY 1A DAP with the one degree deadband. Another way of looking at this is by comparing average RCS propellant consumption rates. The consumption rate for the 1A version of the DAP in P64 and P65 was 0.0416 lb/sec while the 1B DAP had a consumption rate of 0.104 lb/sec, which is an increase of about 150 percent (the pitchover maneuvers were included in the calculations of these rates). At first glance, this increase in propellant consumption rate appears somewhat high, however the actual mission impact is really very small. The reason for this is that the actual amount of propellant being consumed for automatic control is quite small. An increase from roughly seven pounds to fourteen pounds does not severely impact the RCS budget. It should also be kept in mind that the propellant figures obtained in the simulations are very sensitive to the slosh model. Also, the GTS-slosh-RCS interaction and phasing can cause variations from run to run. Two runs which have only minor differences between them can produce RCS propellant consumptions which differ by 15 to 20 percent.

The performance of the LUMINARY 1B, DAP is considered satisfactory for the nominal descent test case. The vehicle oscillations present during powered descent are not considered to be excessive based on this test run. The magnitudes of the slosh oscillations were reduced when the deadband was switched to 0.3 degree.

FIGURE 1

INNER GIMBAL ANGLE, CDUY

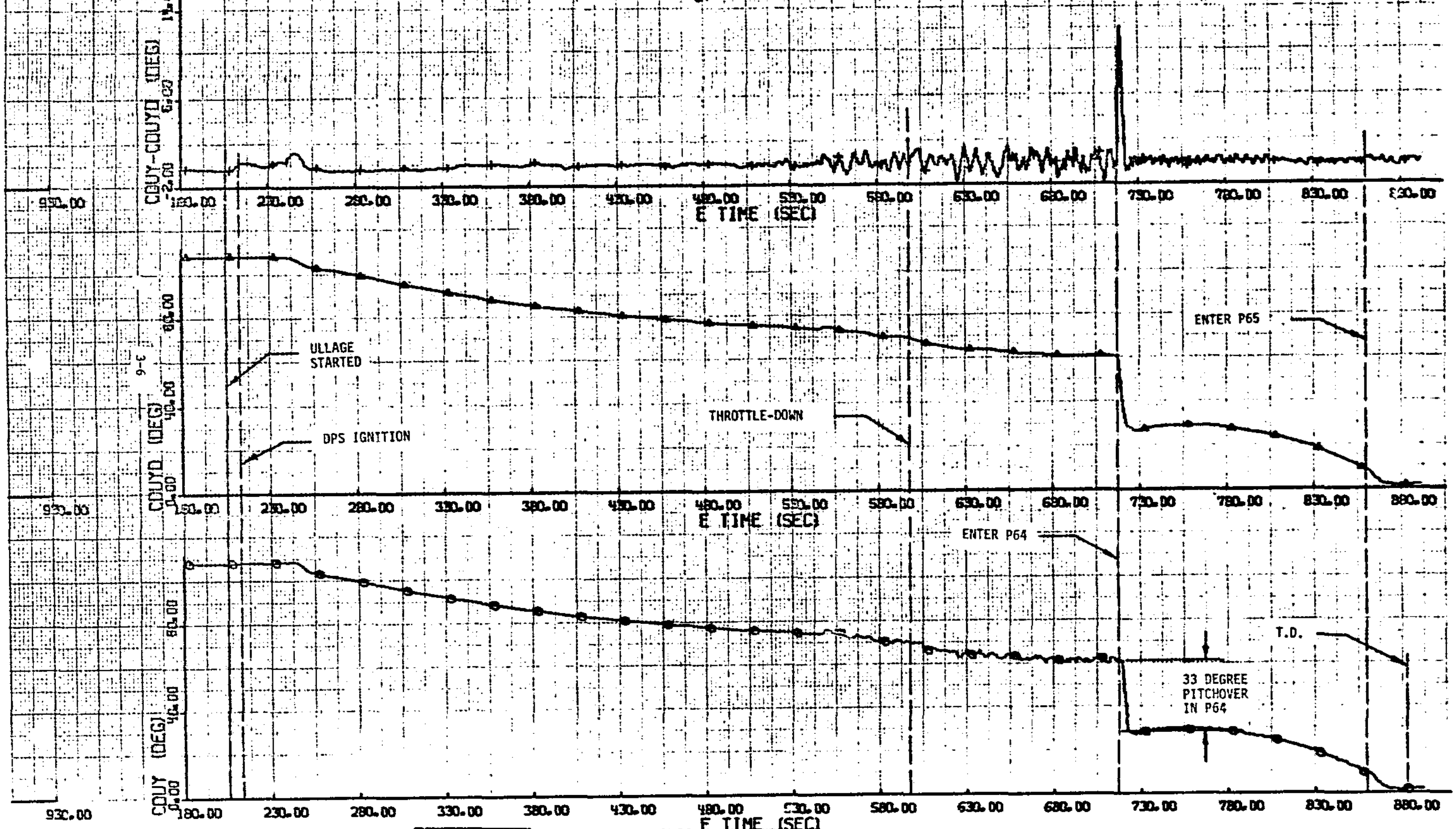


FIGURE 2

PITCH, YAW, AND ROLL ATTITUDE ERRORS

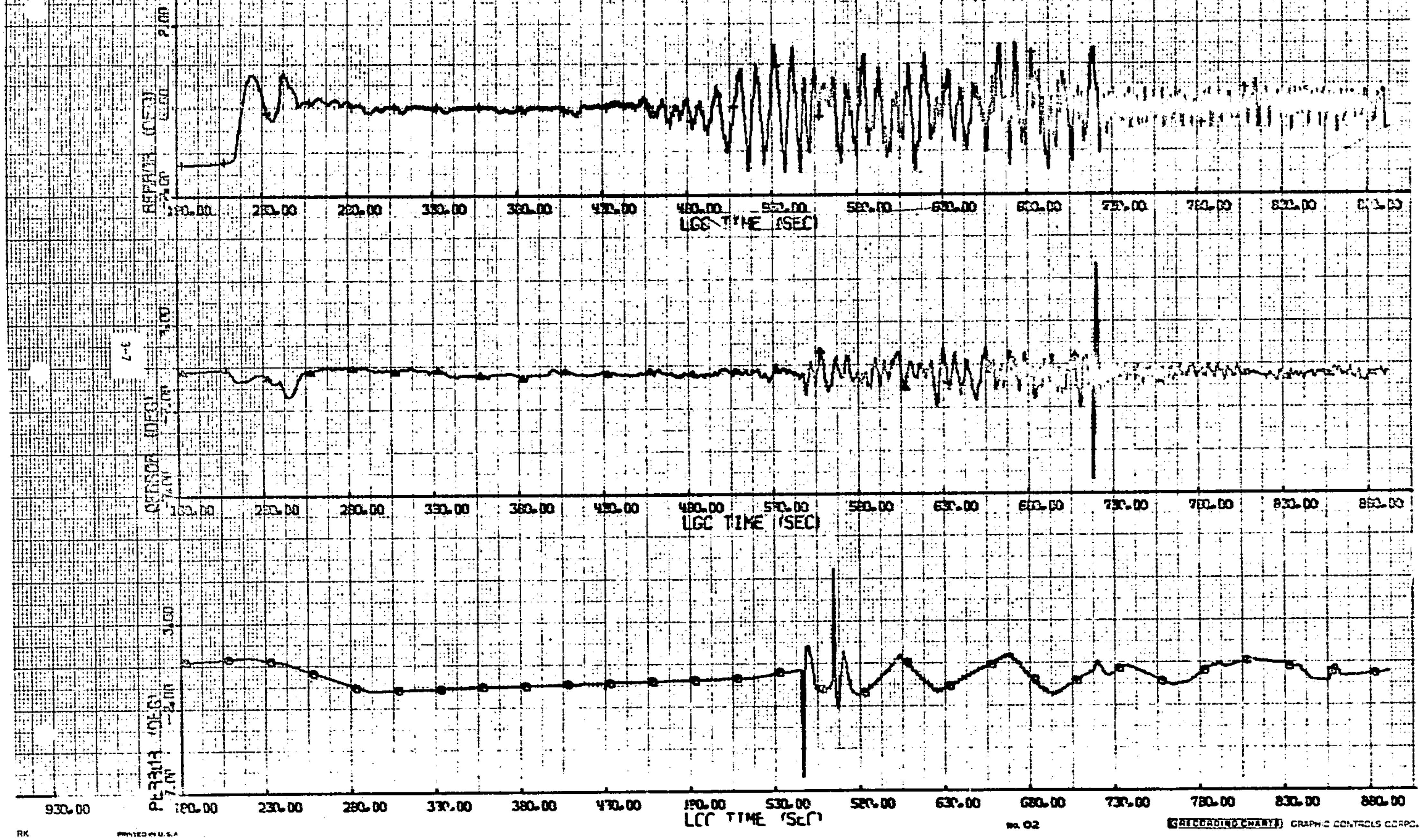
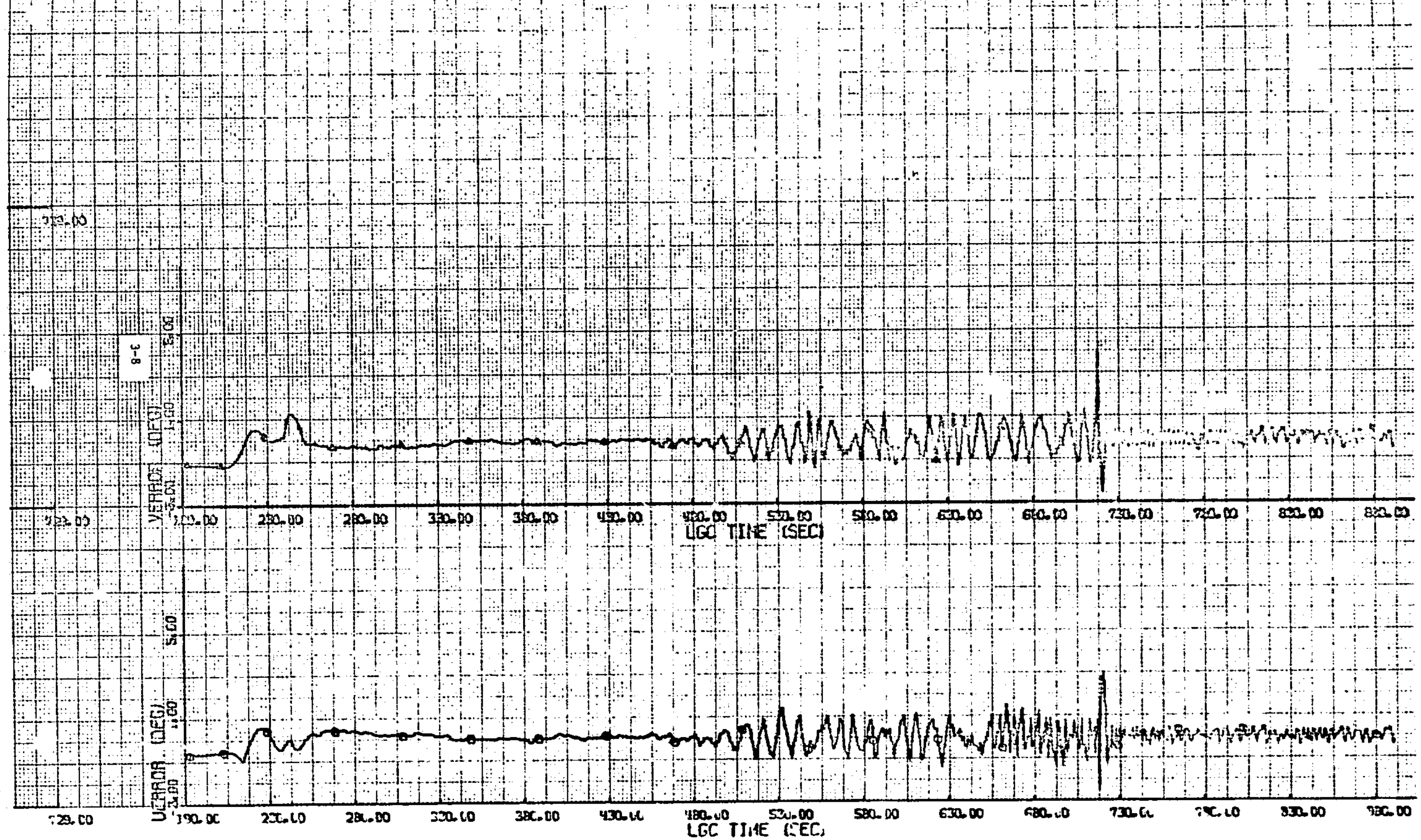


FIGURE 3

U', V' CONTROL AXES ATTITUDE ERRORS



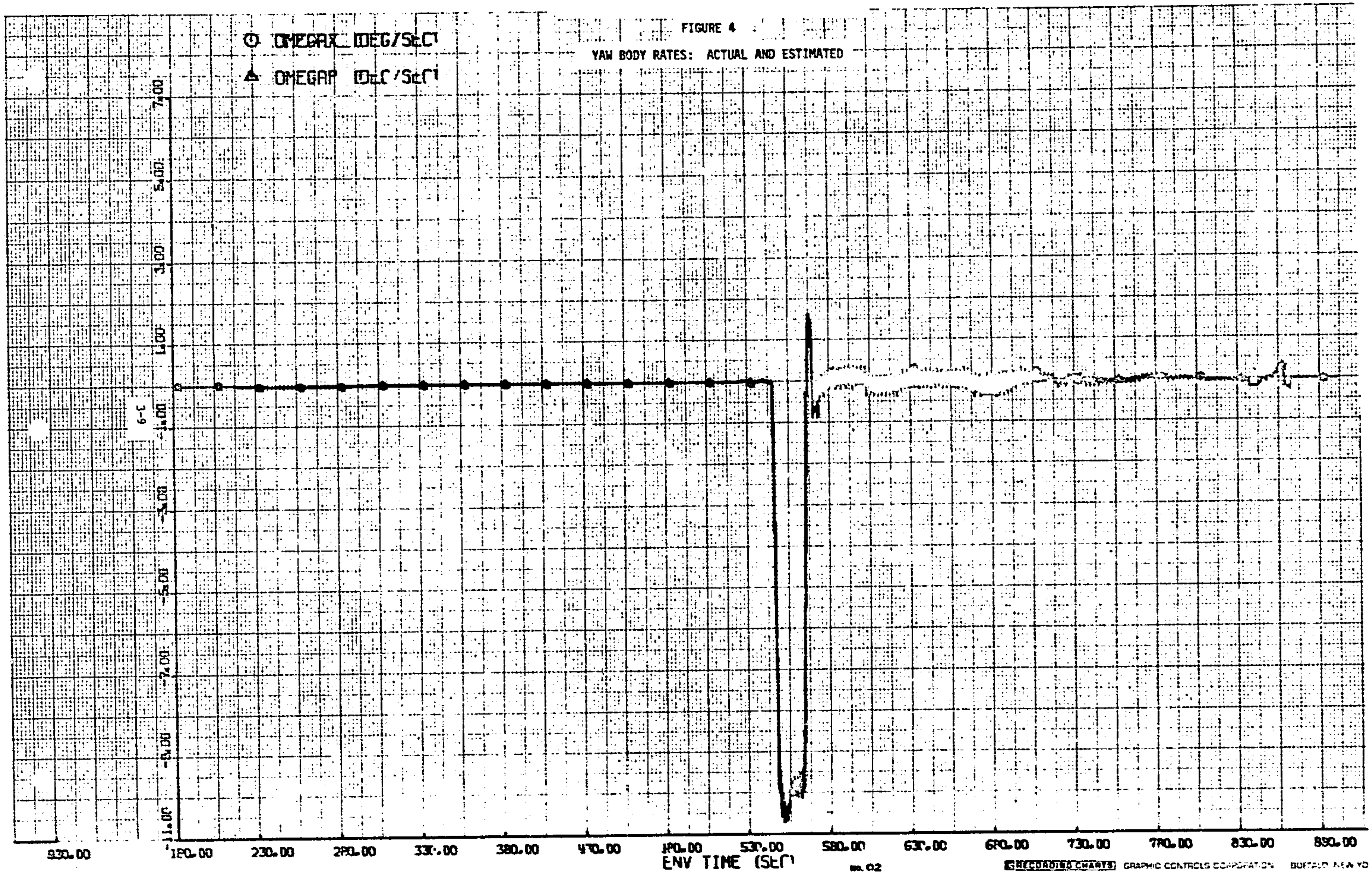
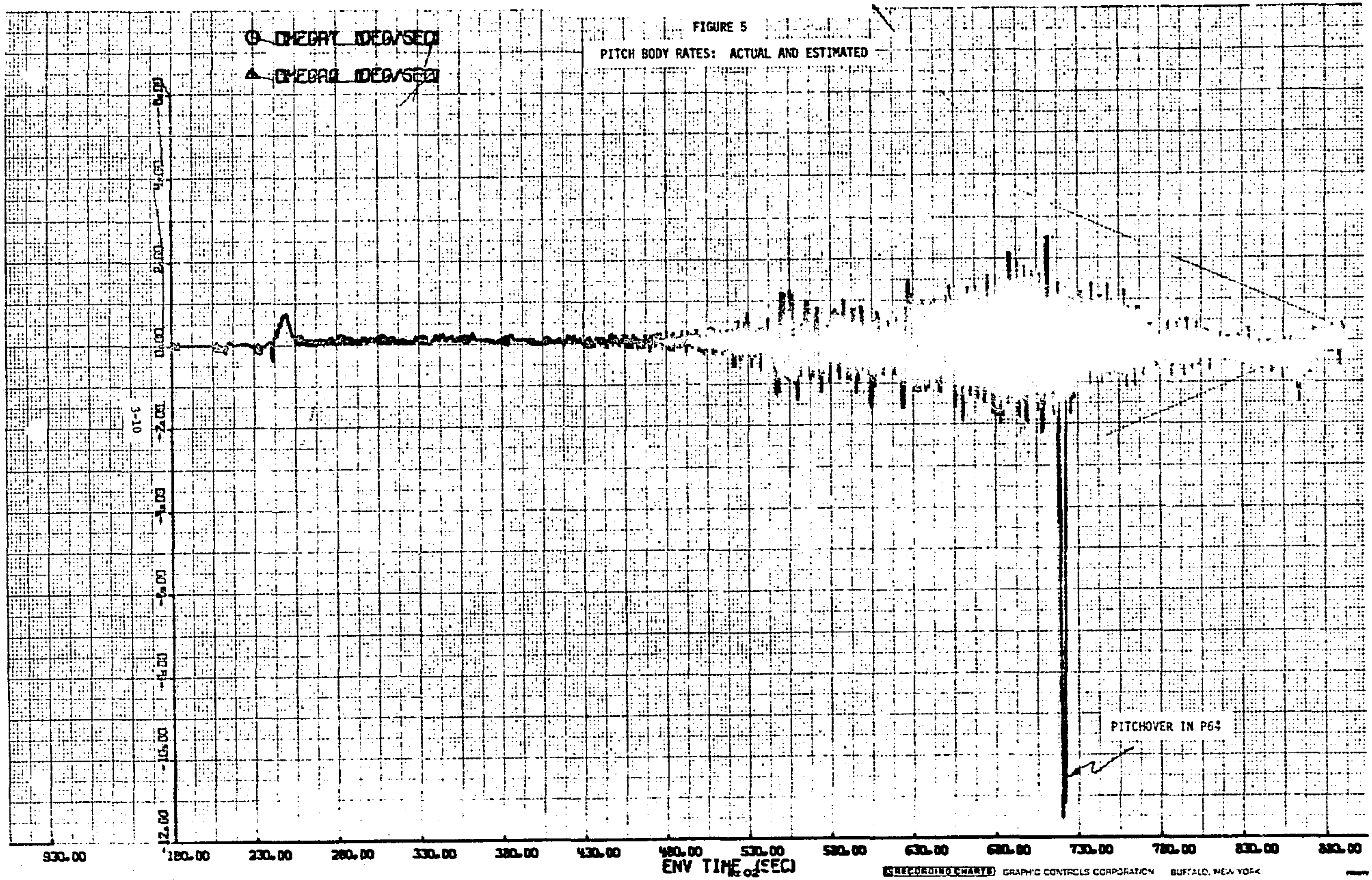


FIGURE 4

YAW BODY RATES: ACTUAL AND ESTIMATED

FIGURE 5

PITCH BODY RATES: ACTUAL AND ESTIMATED



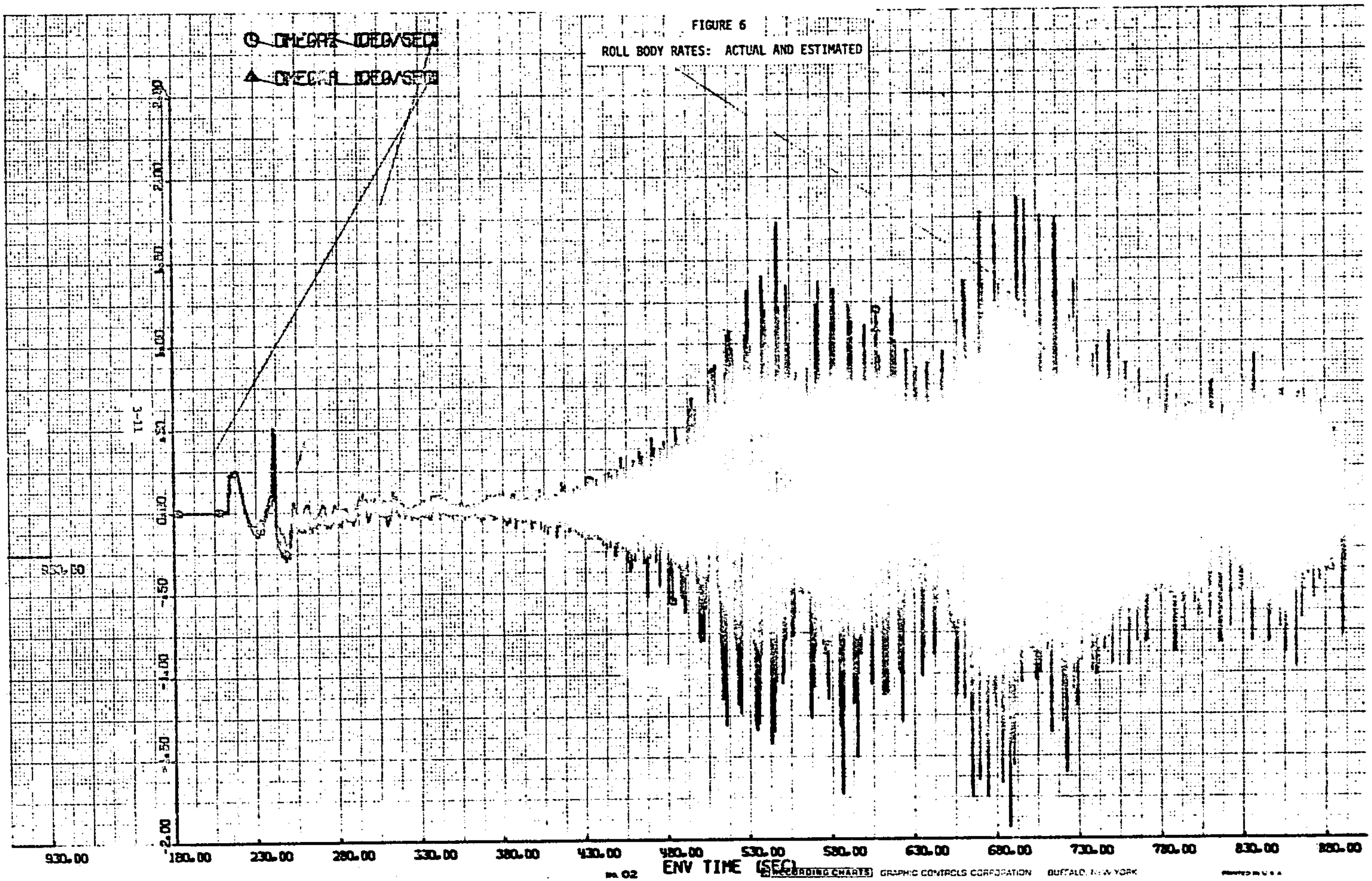


FIGURE 6

ROLL BODY RATES: ACTUAL AND ESTIMATED

FIGURE 7

RATE ERRORS: U', V' - AXES

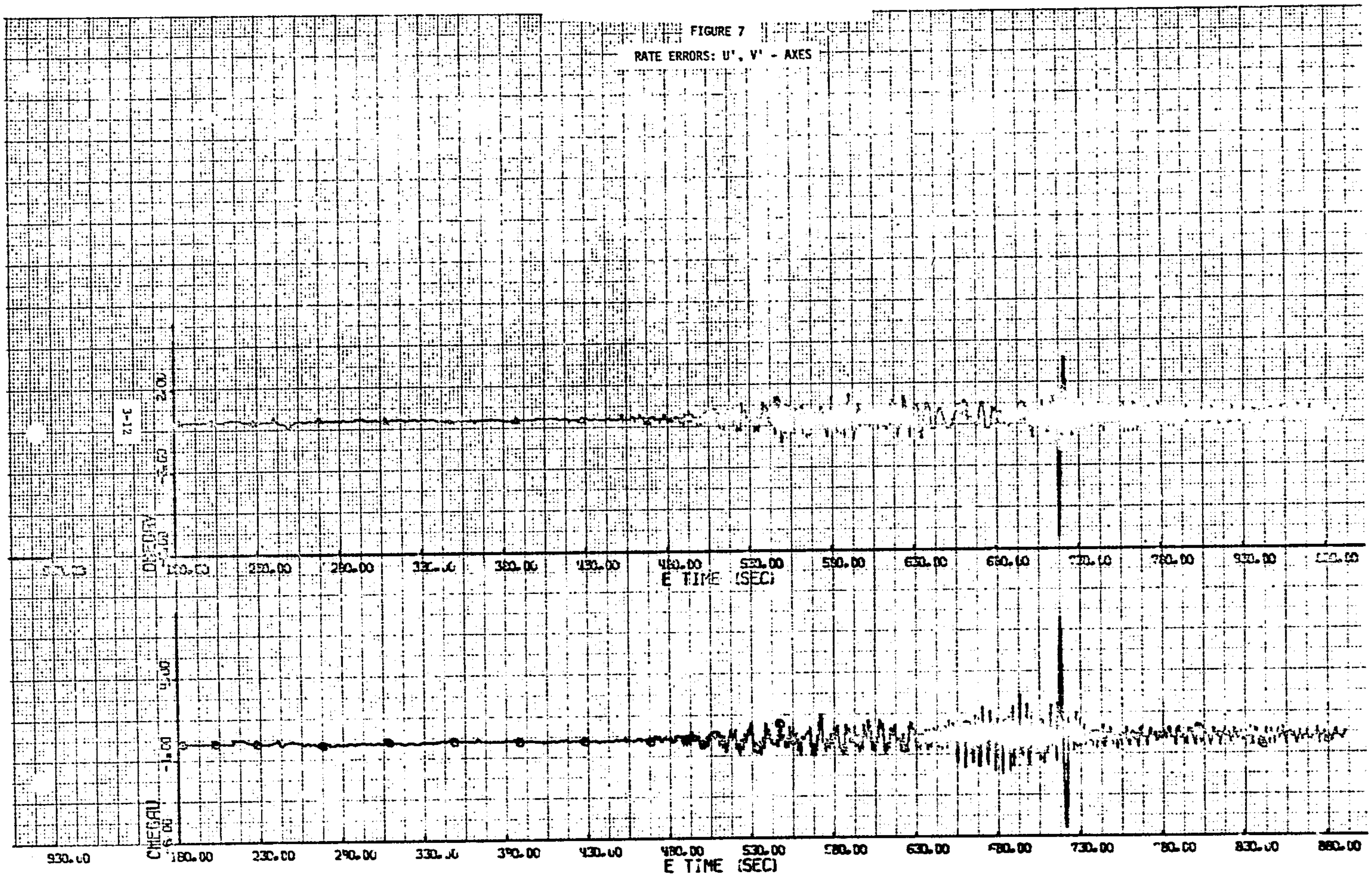
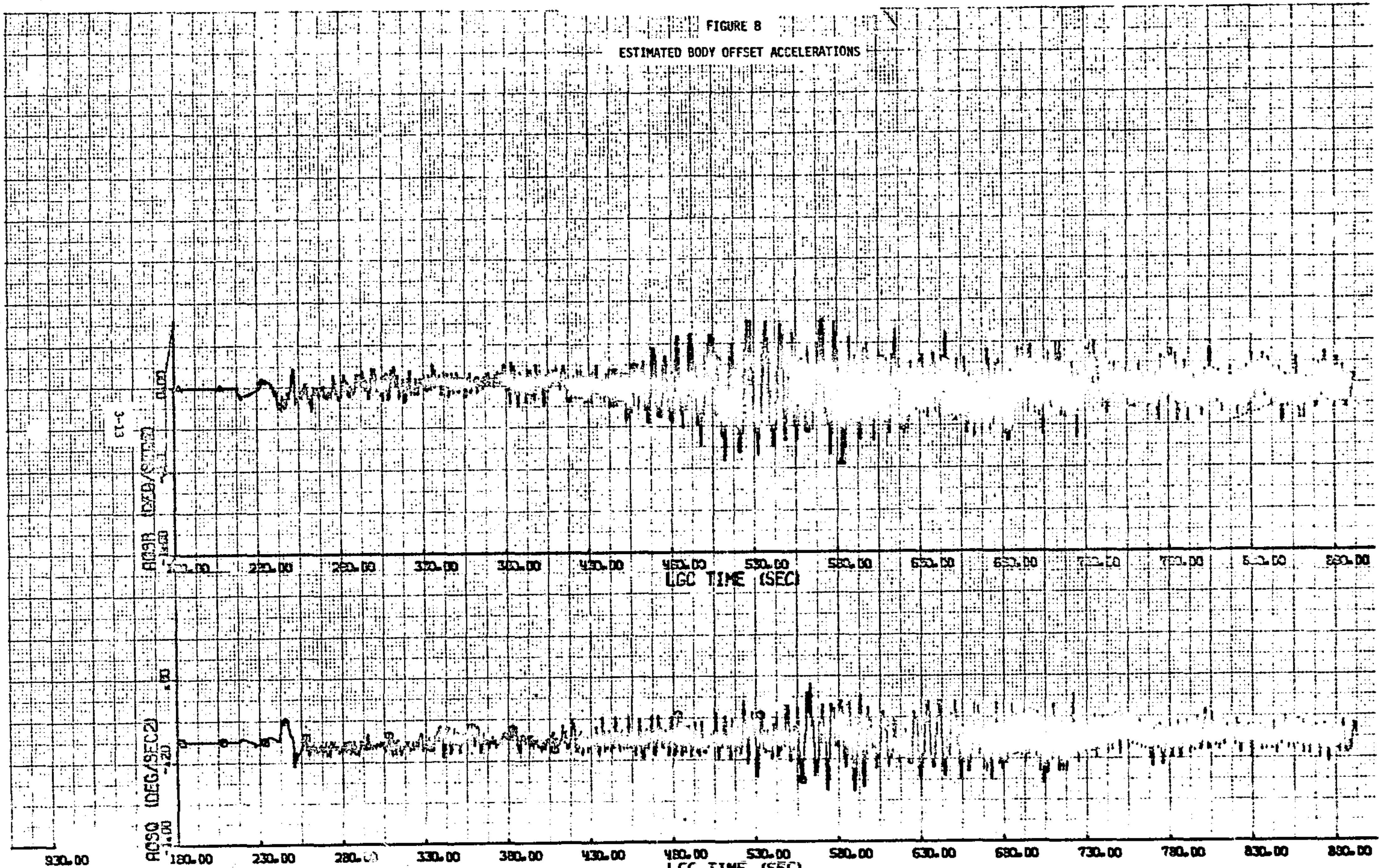


FIGURE 8

ESTIMATED BODY OFFSET ACCELERATIONS



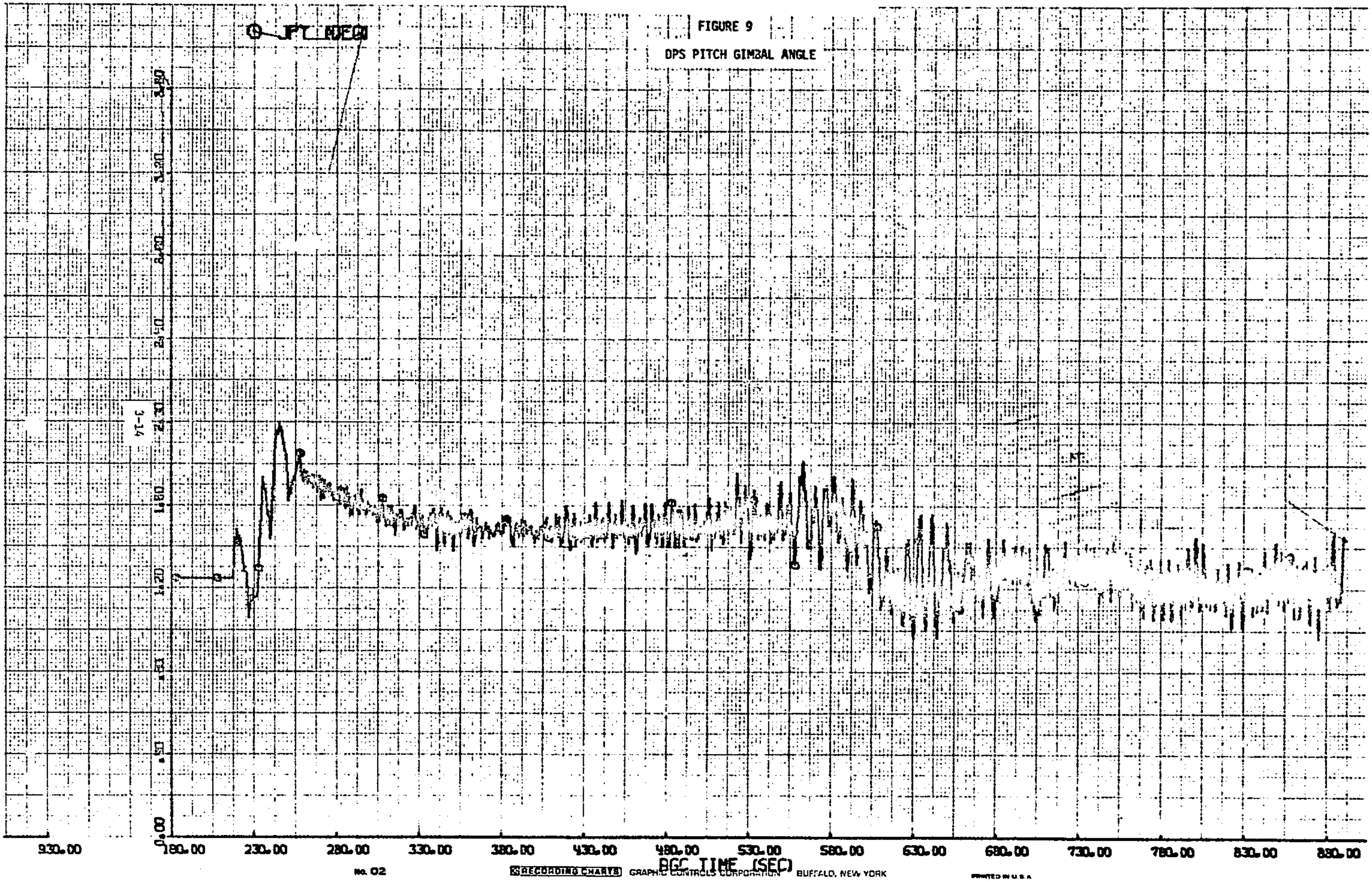


FIGURE 9

DPS PITCH GIMBAL ANGLE

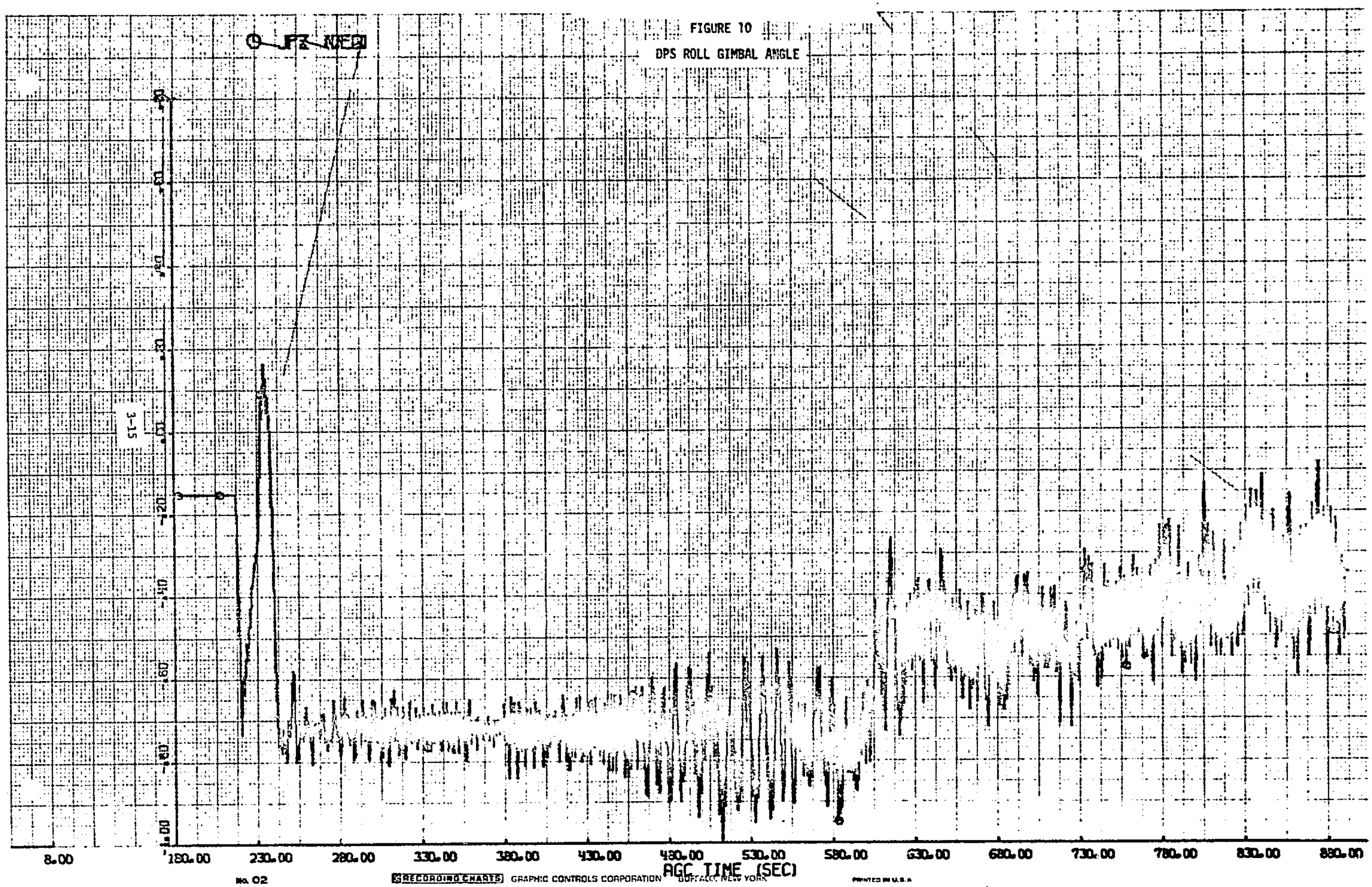


FIGURE 10

DPS ROLL GIMBAL ANGLE

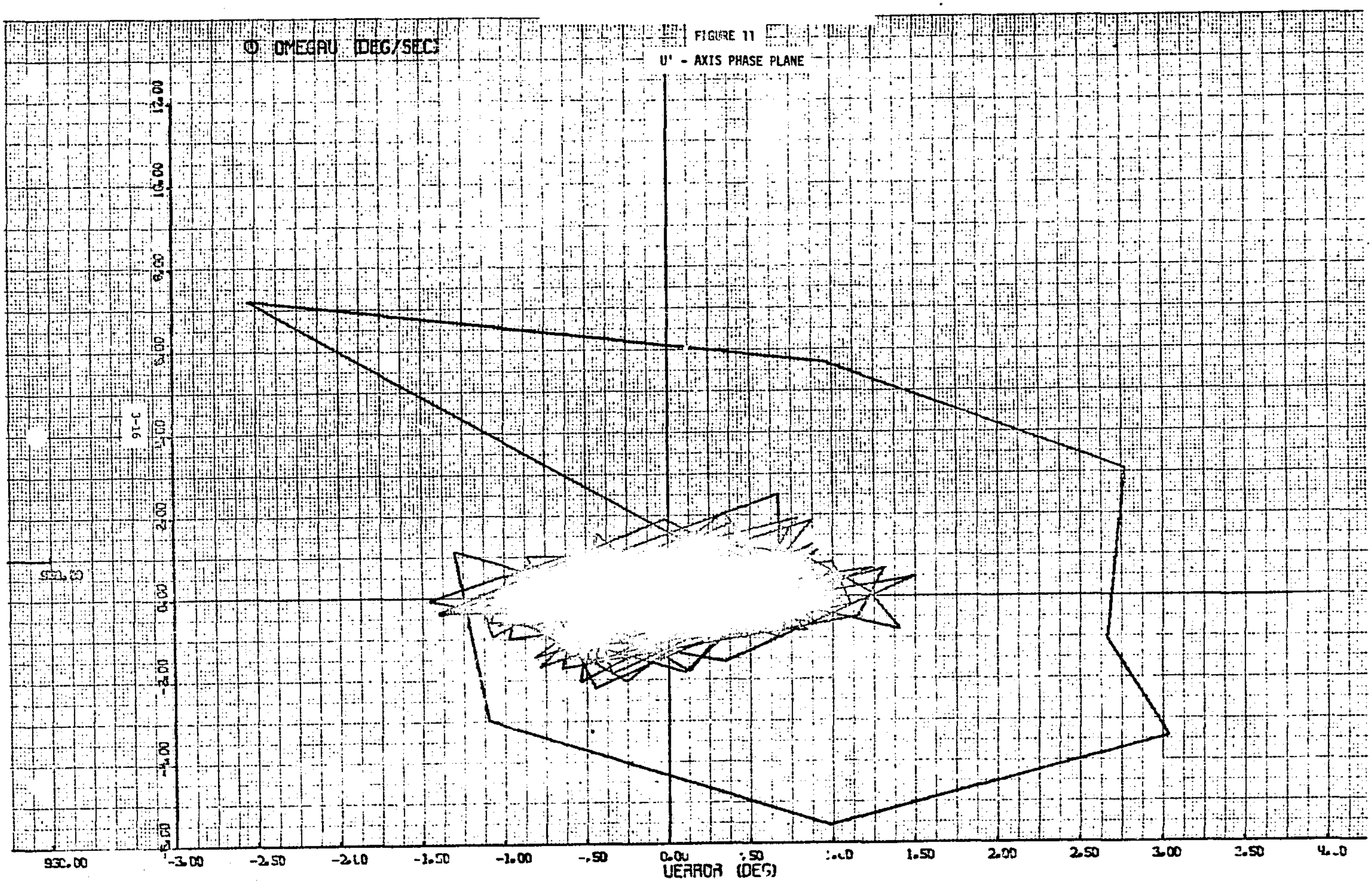


FIGURE 11

U' - AXIS PHASE PLANE

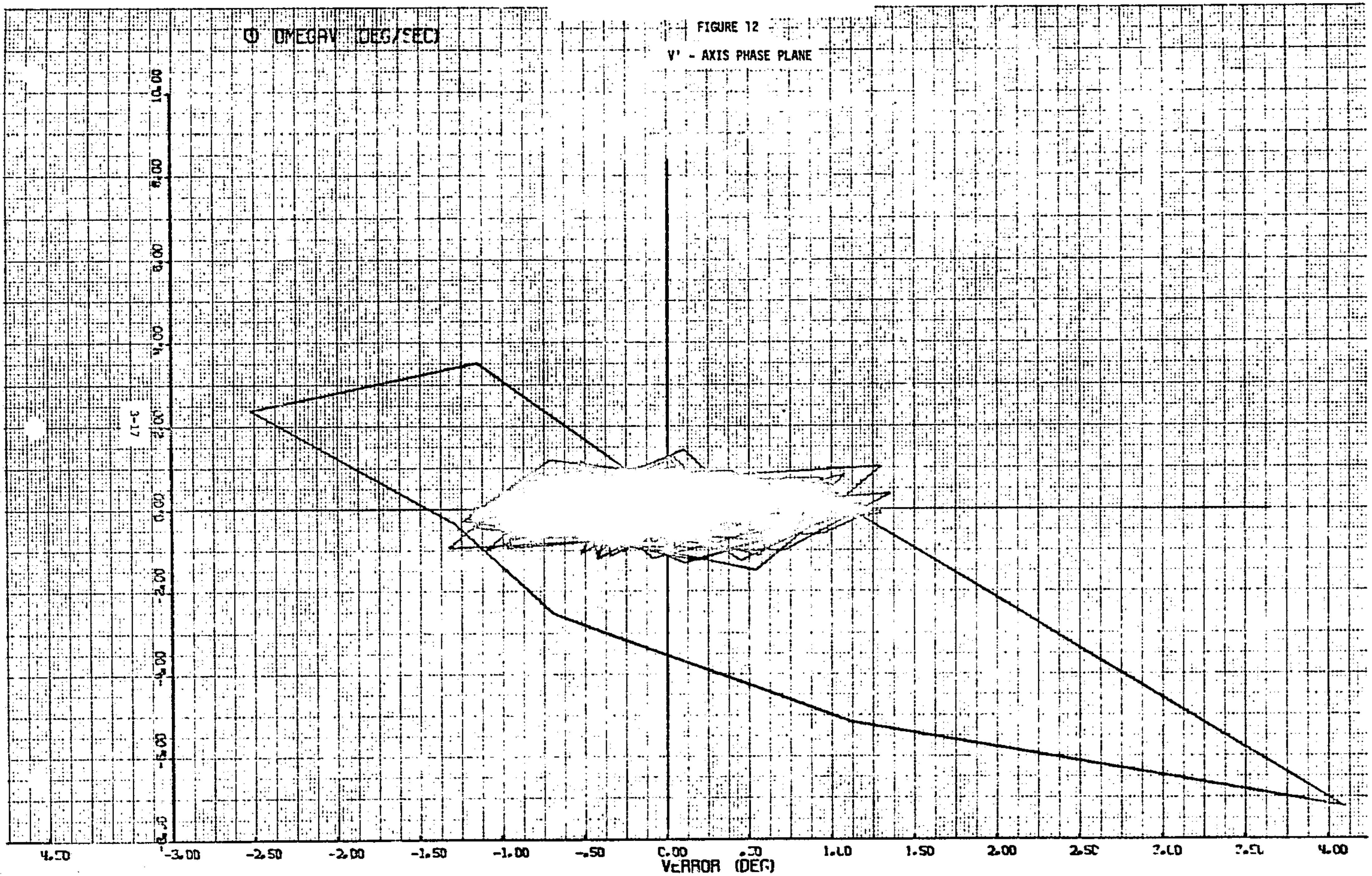


FIGURE 12

V' - AXIS PHASE PLANE

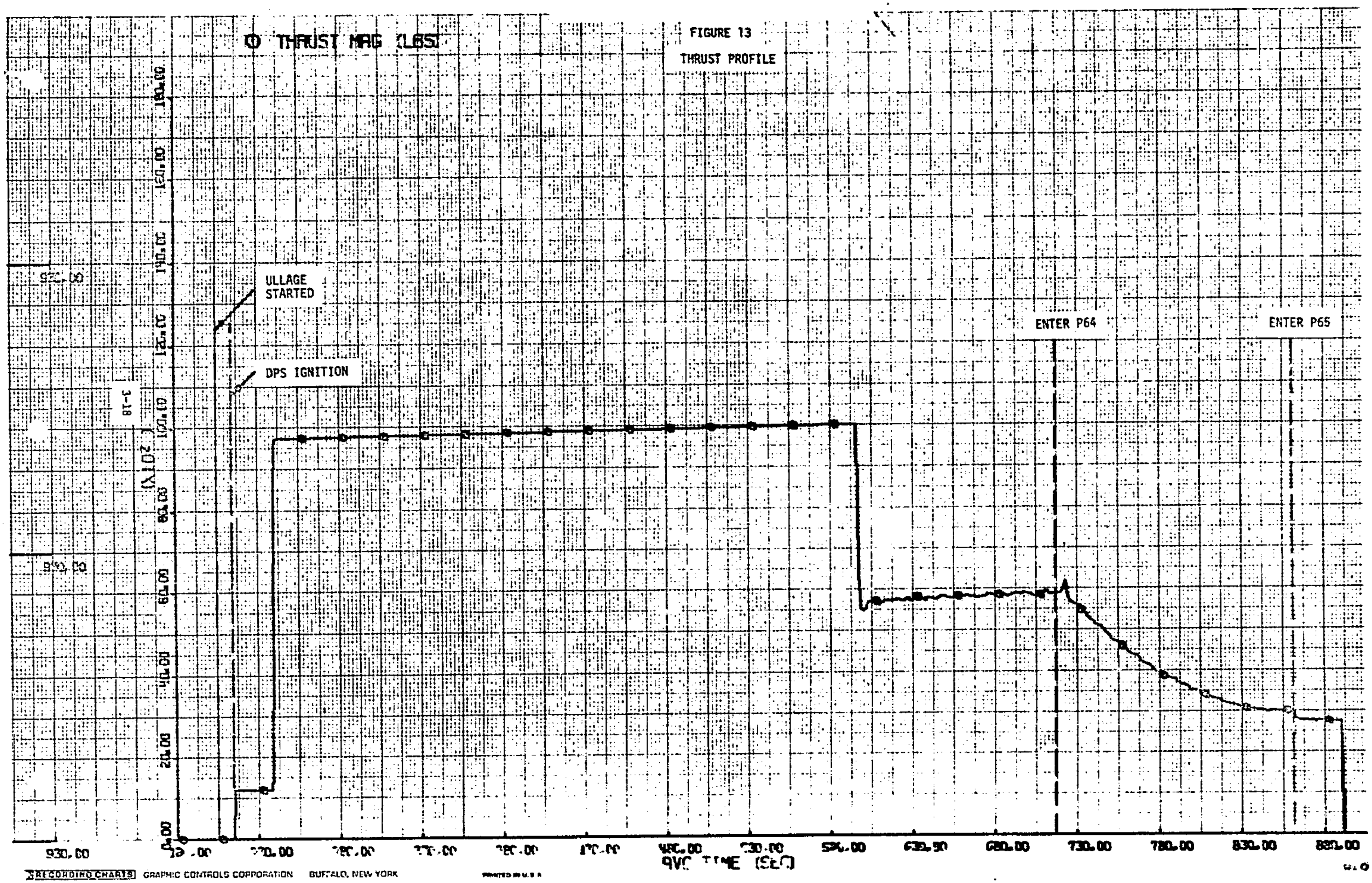


FIGURE 13
THRUST PROFILE

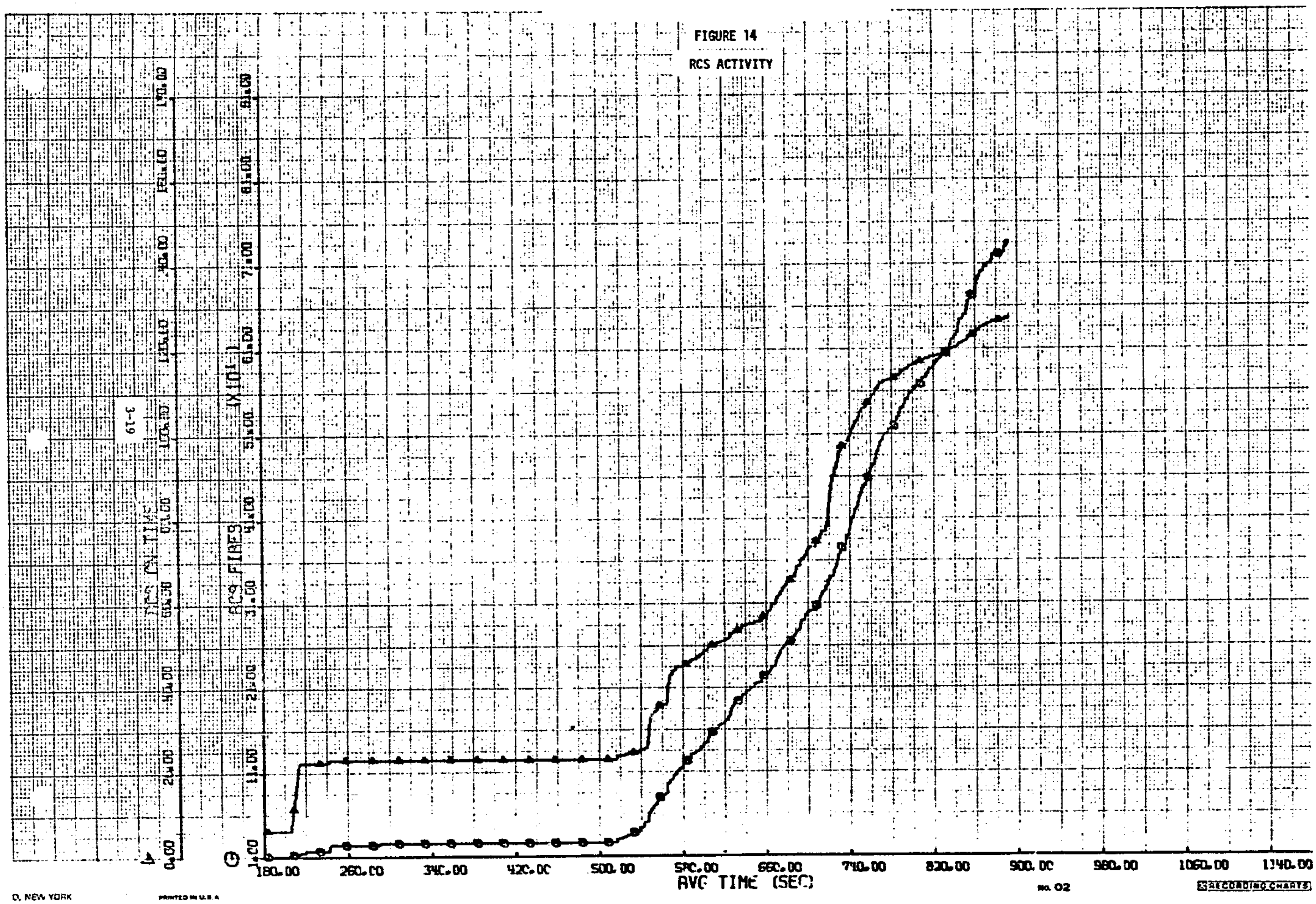
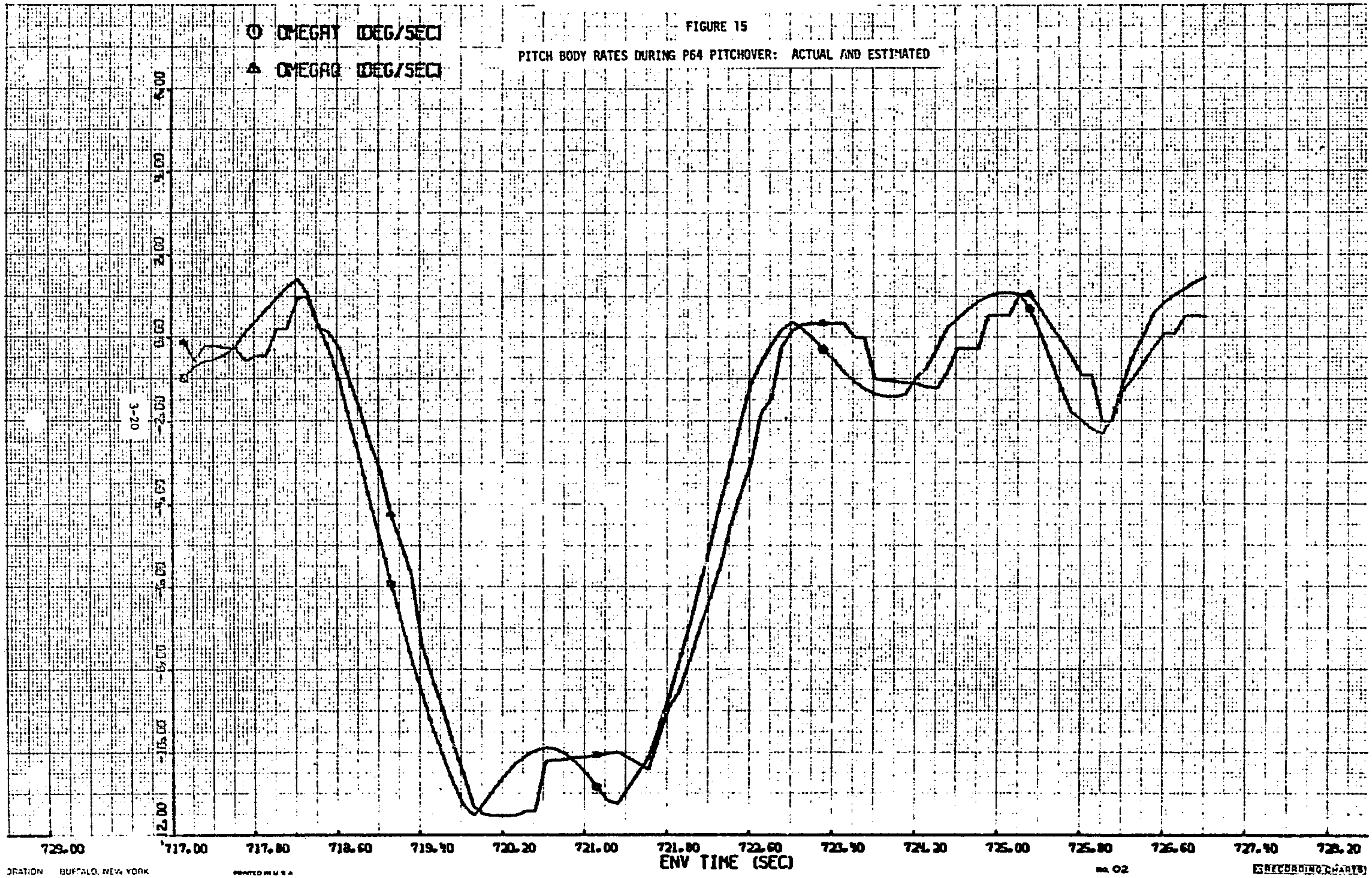


FIGURE 14

RCS ACTIVITY

FIGURE 15

PITCH BODY RATES DURING P64 PITCHOVER: ACTUAL AND ESTIMATED



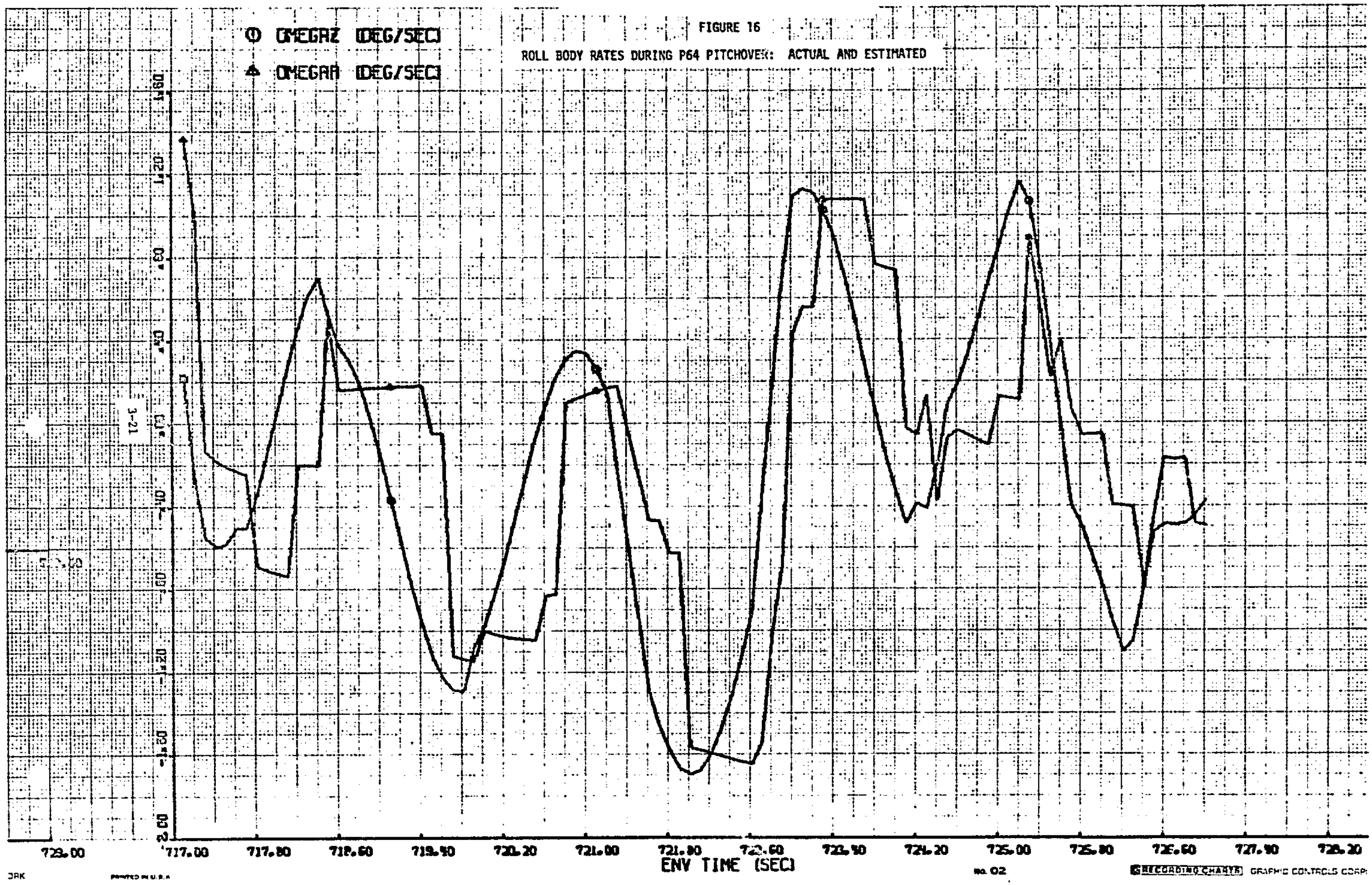


FIGURE 16

ROLL BODY RATES DURING P64 PITCHOVER: ACTUAL AND ESTIMATED

3.2 OFF-NOMINAL DESCENT, RUN H1-1.2

Test Description

This run was similar to Run H1-1.0 except a three-sigma position error (0.3 inch) was used for each RCS quad. The direction of the position error was such as to increase the control effectiveness of the X-axis firing jets. Jet number 1 was also failed off undetected in P63 prior to the pitchover maneuver and remained off for the rest of the run.

Test Objective

Evaluate the DAP performance in an off-nominal descent sequence. Observe the effect of a failed-off jet on the pitchover maneuver and assess the effect of the RCS quad position errors.

Initialization Data

The off-nominal descent test case begins from a nominal descent orbit with the following parameter values just before ignition:

Initial Vehicle Weight and Configuration:

LM-alone, descent and ascent stages
Total Weight = 33125.061 lbs

Center of Gravity Location:

$$\begin{bmatrix} CGX \\ CGY \\ CGZ \end{bmatrix} = \begin{bmatrix} 187.068 \\ 0.086 \\ 0.721 \end{bmatrix} \text{ inches (LM-coordinates)}$$

Inertia Matrix:

$$[I] = \begin{bmatrix} I_{xx} & I_{xy} & I_{xz} \\ I_{yx} & I_{yy} & I_{yz} \\ I_{zx} & I_{zx} & I_{zz} \end{bmatrix} = \begin{bmatrix} 23028.303 & -94.058 & -616.228 \\ -94.058 & 25026.685 & -272.780 \\ -616.228 & -272.780 & 25054.128 \end{bmatrix} \text{ slug-ft}^2$$

Initial Attitude and Rate Errors:

$$\begin{bmatrix} PERROR \\ QERROR \\ RERROR \end{bmatrix} = \begin{bmatrix} 0.75 \\ 0.5 \\ -1.0 \end{bmatrix} \text{ deg}$$

$$\begin{bmatrix} OMEGAP \\ OMEGAQ \\ OMEGAR \end{bmatrix} = \begin{bmatrix} 0.006 \\ 0.011 \\ 0.004 \end{bmatrix} \text{ deg/sec}$$

DPS Gimbal Angles:

1) At beginning of simulation

$$\begin{bmatrix} JPY \\ JPZ \end{bmatrix} = \begin{bmatrix} 1.247 \\ -0.151 \end{bmatrix} \text{deg}$$

2) Theoretical trim angles for initial c.g. location

$$\begin{bmatrix} JPY \\ JPZ \end{bmatrix} = \begin{bmatrix} 1.247 \\ -0.151 \end{bmatrix} \text{deg}$$

Simulation Options Exercised:

1) Compliance effects of DPS mounting structure
2) Fuel slosh effects (old linear slosh model)
3) RCS jet deflectors
4) 3 sigma RCS quad position error
5) Jet 1 failed off at pitchover

Fuel Loadings:

DPS fuel loading =	17,588	lbs	(100%)
APS fuel loading =	5,078	lbs	(100%)

Ullage Used:

1) Type = two jet (6, 14)
2) Duration = 8 sec

Timeline

The following is a list of the major events and their times of occurrence.

	Time-Seconds	Event
1)	205.0575	Ullage Initiated
2)	212.5605	DPS Engine Ignition Command
3)	213.0564	Ullage Completed
4)	685.0000	Jet number 1 failed off
5)	717.0797	Enter Visibility Phase Program, P64
6)	861.2888	Enter Automatic Landing Program, P65
7)	906.5568	LM Stop Button
8)	907.1398	DPS Engine Off
9)	907.5568	Touchdown confirmed

The total time between ignition and lunar touchdown was 694.9963 sec or 11.6 minutes. The plots presented in Figures 17 thru 30 consider only the time interval from ullage to lunar touchdown.

Results

Figures 17 thru 32 are plots of the various LGC and Environment parameters pertinent to this test case. Table 1 indicates the magnitudes and times of occurrence of certain key variables. Table 2 presents a summary of the RCS activity. Data for Figures 17 thru 30 were obtained every fifth DAP cycle or 0.5 sec while data for Figures 31 and 32 were obtained every DAP cycle.

The response of the DAP in P63 for this run is essentially the same as Run H1-1.0. The control effectiveness of the RCS jets has been increased approximately 0.5% by the 3σ position error. Since the DAP has no knowledge of this, the calculated jet on-times are slightly long, thus producing some increase in rates and limit cycle frequencies. It is interesting to note that the cumulative jet on-time in P63 is actually less than the corresponding portion of Run H1-1.0. The reason for this lies in the slosh-GTS-RCS interaction. Large slosh amplitudes generated by the GTS can eventually reach levels that cause RCS jet firings to occur. If the RCS jet firing is in-phase with the slosh, the slosh amplitude can be significantly increased. The large slosh amplitude thus produces an overshoot in the RCS response. Figure 5 shows that a large amplitude, low frequency ($\approx$0.19 Hz) pitch rate oscillation exists from T = 540 sec until T = 715 sec. The corresponding portion of Figure 21 shows that the oscillations for the off-nominal case are not as sustained and thus produced fewer long duration RCS firings. The phasing between the RCS, GTS, and slosh can cause variations from run to run. It should not be misconstrued that increasing the RCS control authority would be a solution to this interaction problem.

The pitchover maneuver for this test case was performed slower and at a lower rate than the nominal case because of the failed-off jet. Figure 22 shows that a sizeable rate was induced in the roll axis during pitchover. This was due to the moment imbalance caused by the failed jet and the cross coupling between the axes. The pitchover maneuver was accomplished satisfactorily and the remaining portion of the burn was very similar to the nominal case. The DAP tried to use Jet 1 a total of nine times during the period in which it was failed.

Satisfactory DAP performance was obtained when a single jet was failed off undetected and the RCS quads were misaligned. The magnitudes of the vehicle oscillations obtained for this run were comparable to those obtained in the nominal run.

FIGURE 17

INNER GIMBAL ANGLE, CDUY

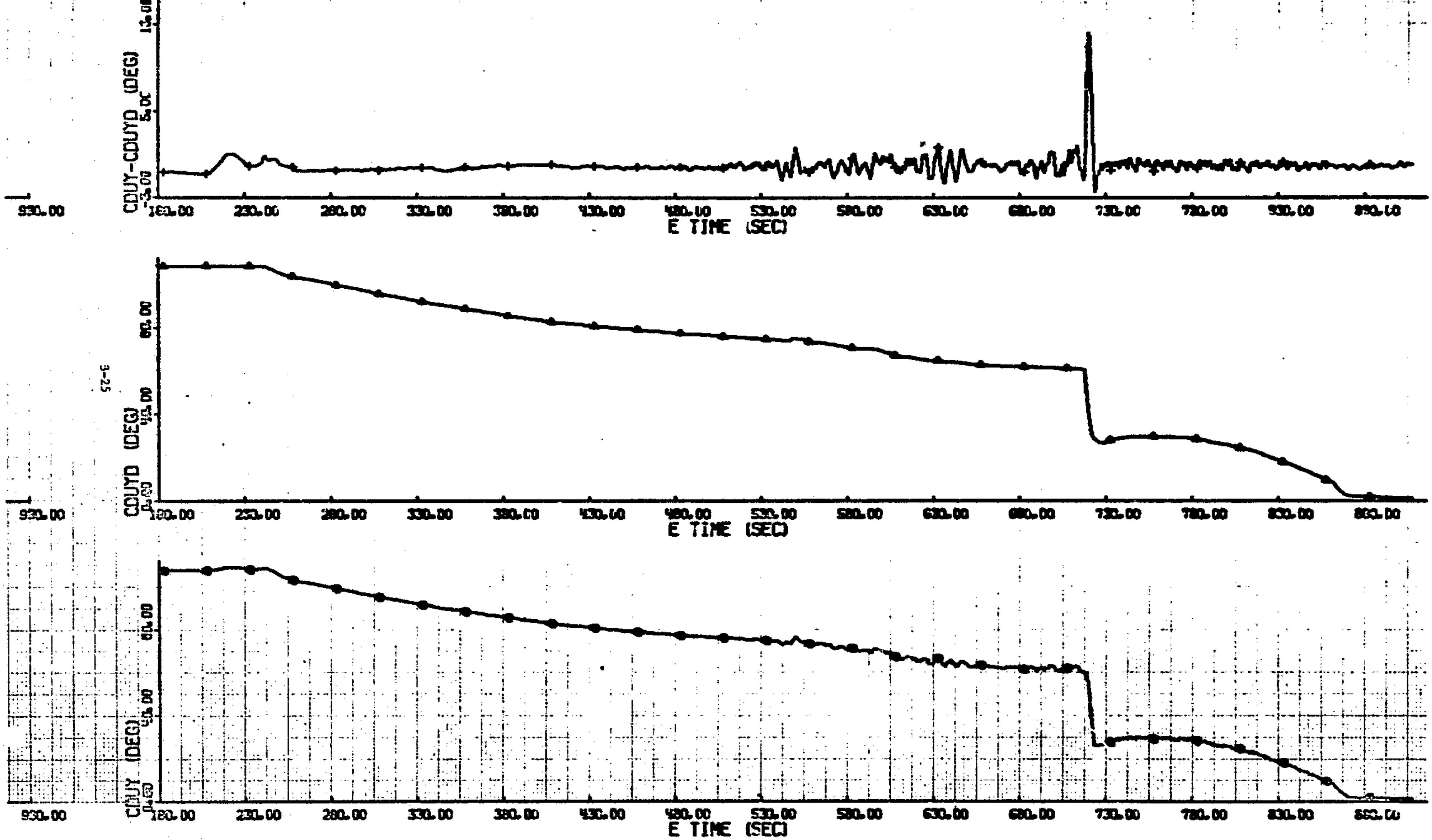


FIGURE 18

PITCH, YAW, AND ROLL ATTITUDE ERRORS

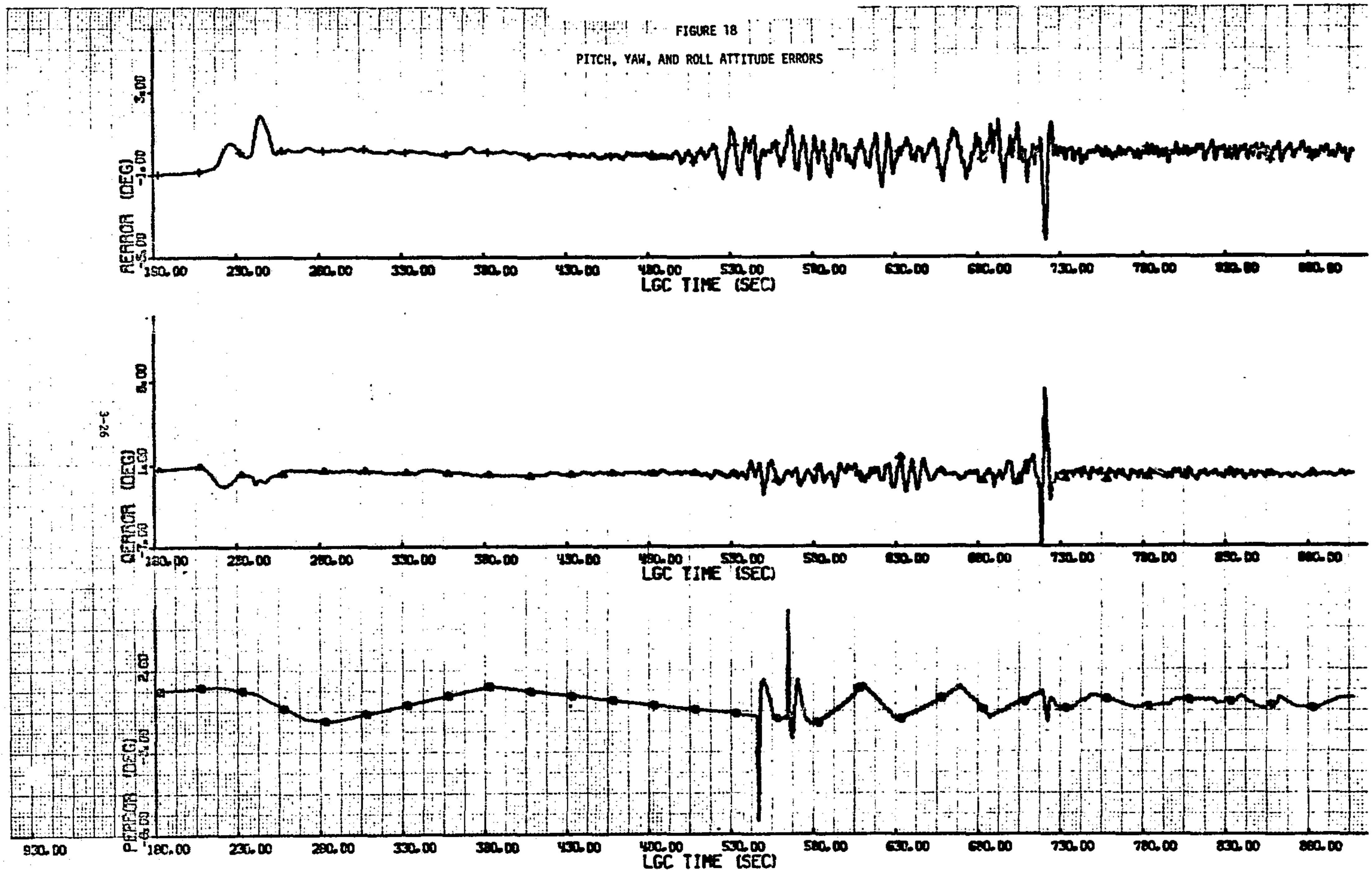


FIGURE 19

U', V' CONTROL AXES ATTITUDE ERRORS

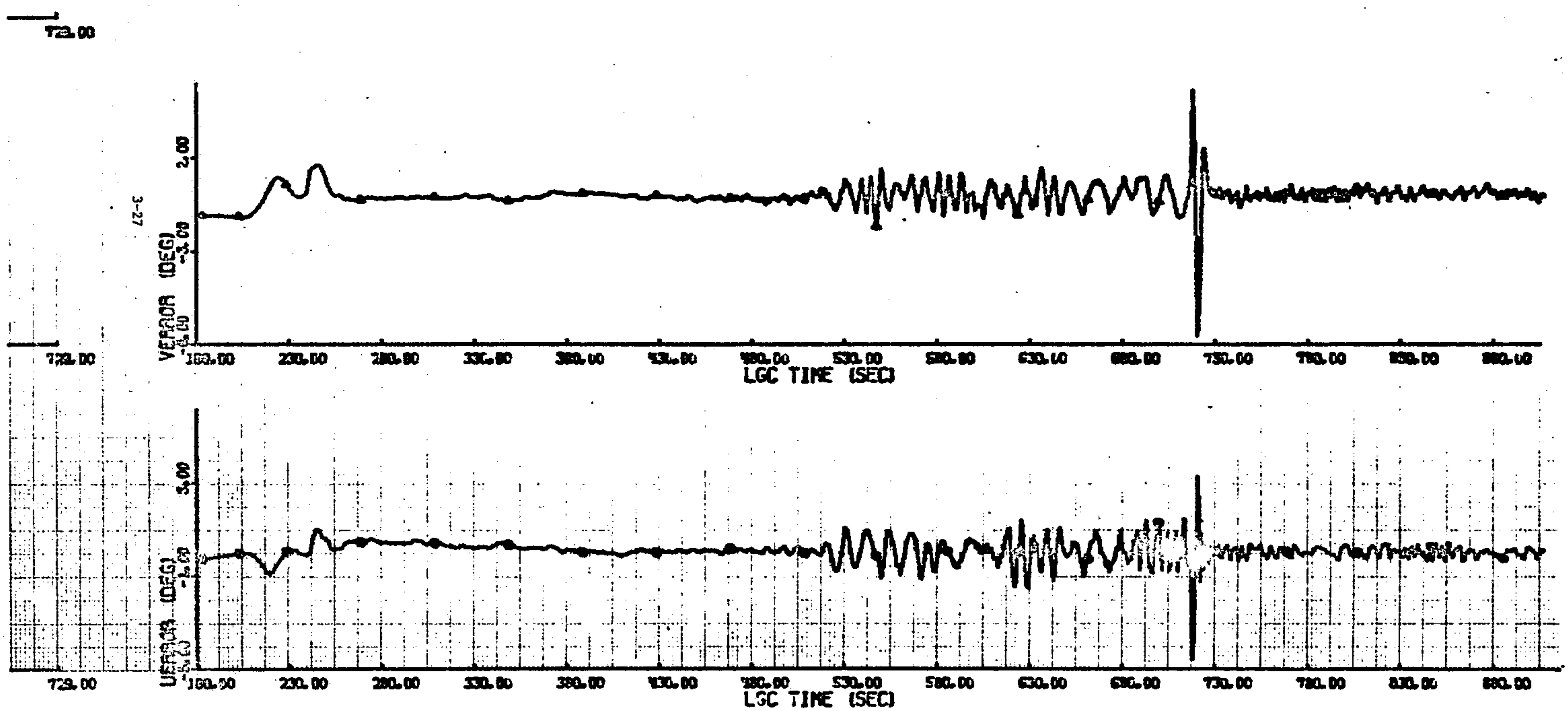


FIGURE 20

YAW BODY RATES: ACTUAL AND ESTIMATED

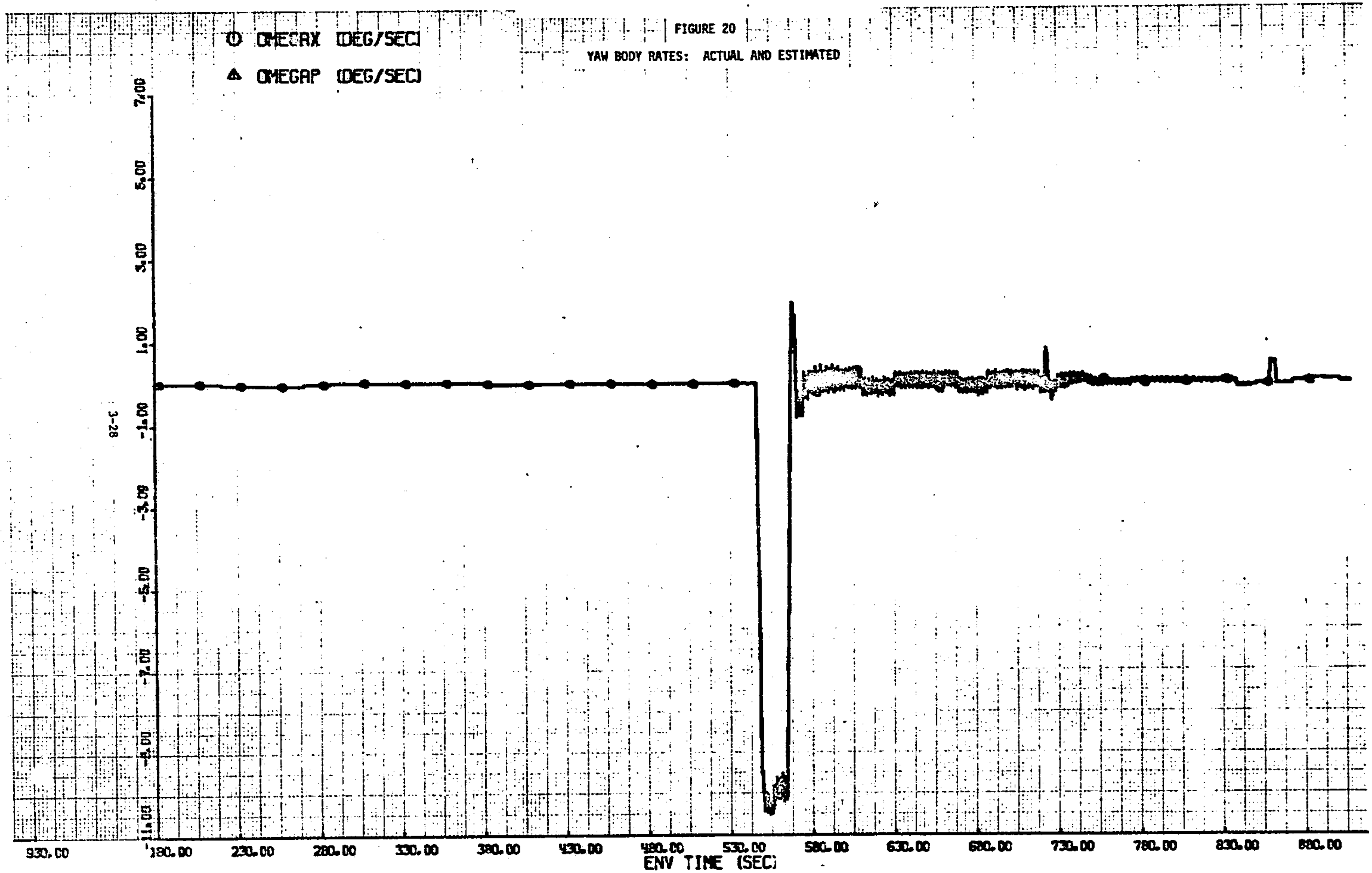


FIGURE 21

PITCH BODY RATES: ACTUAL AND ESTIMATED

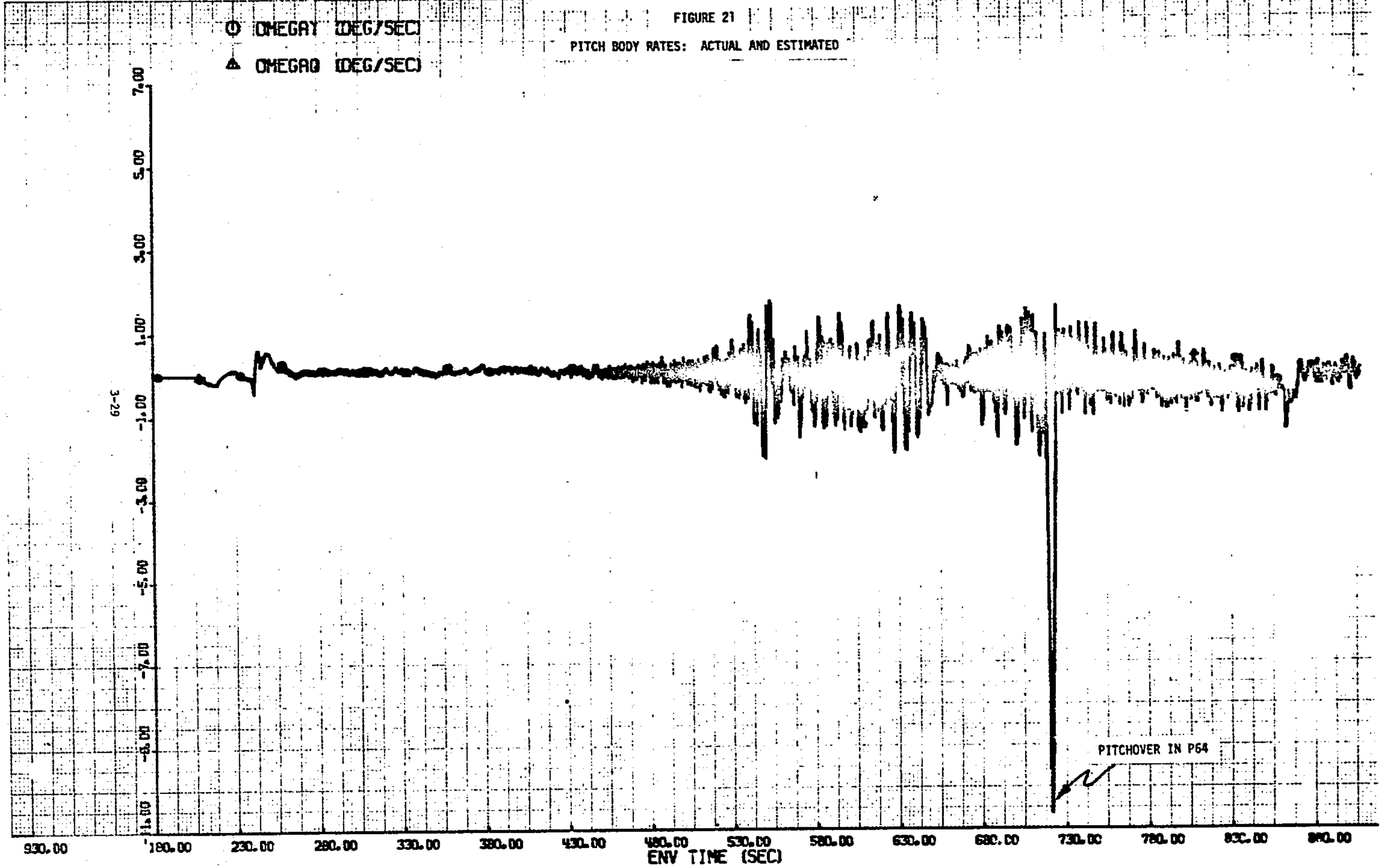


FIGURE 22

ROLL BODY RATES: ACTUAL AND ESTIMATED

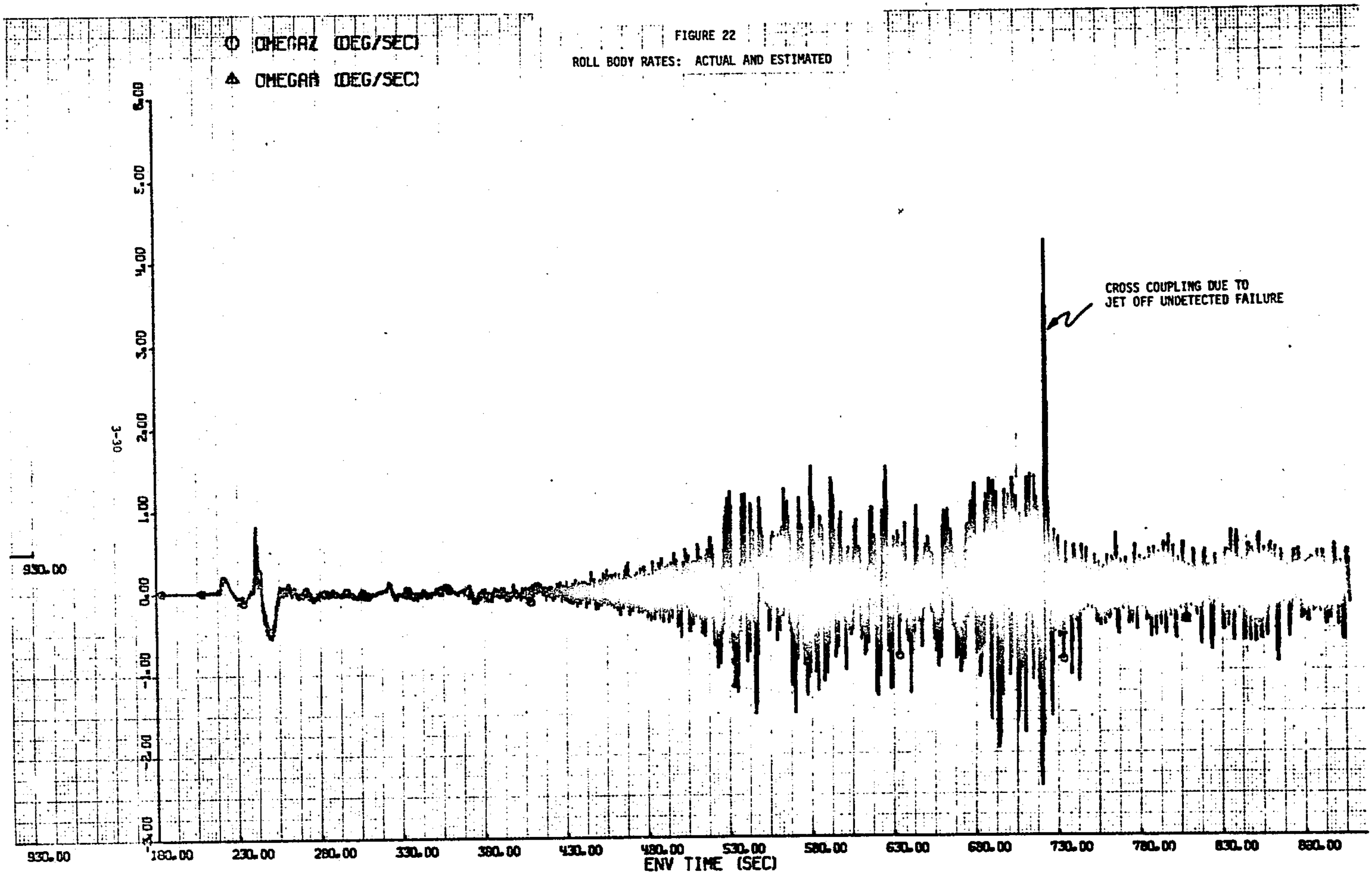


FIGURE 23

RATE ERRORS: U', V' - AXES

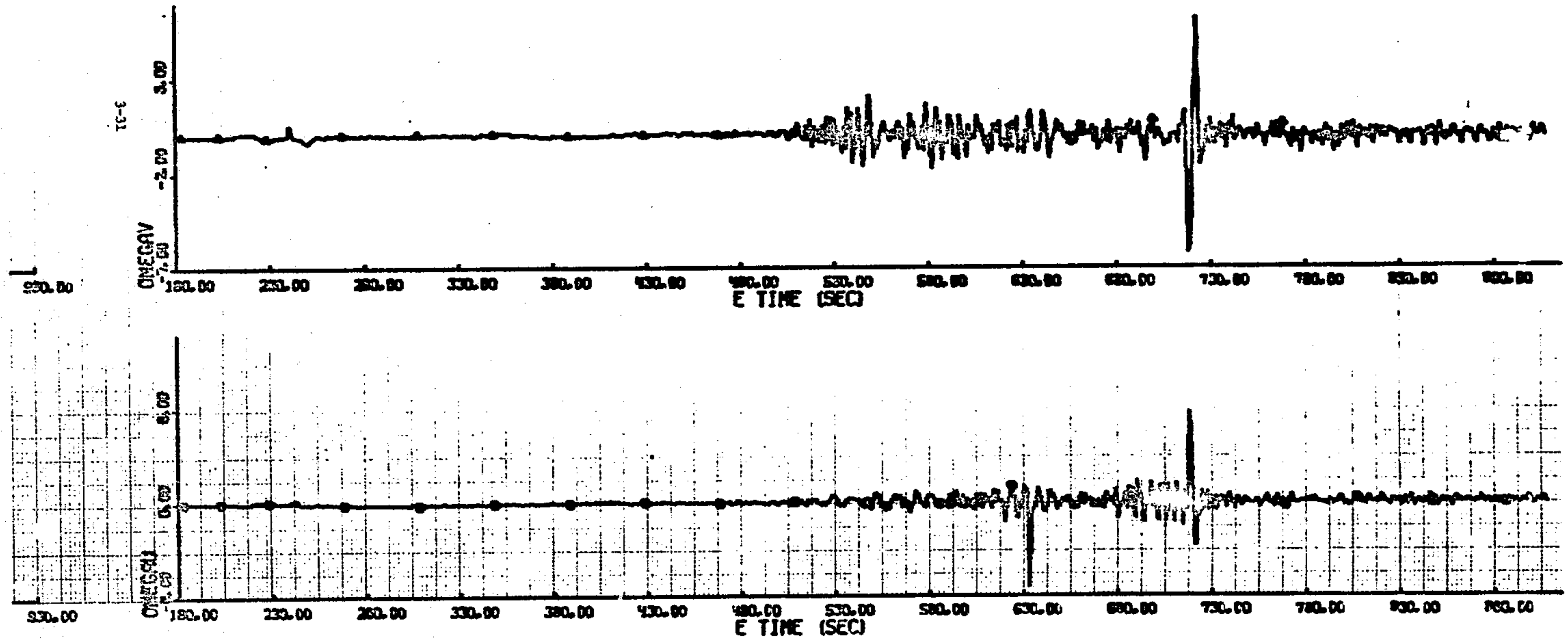


FIGURE 24

ESTIMATED BODY OFFSET ACCELERATIONS

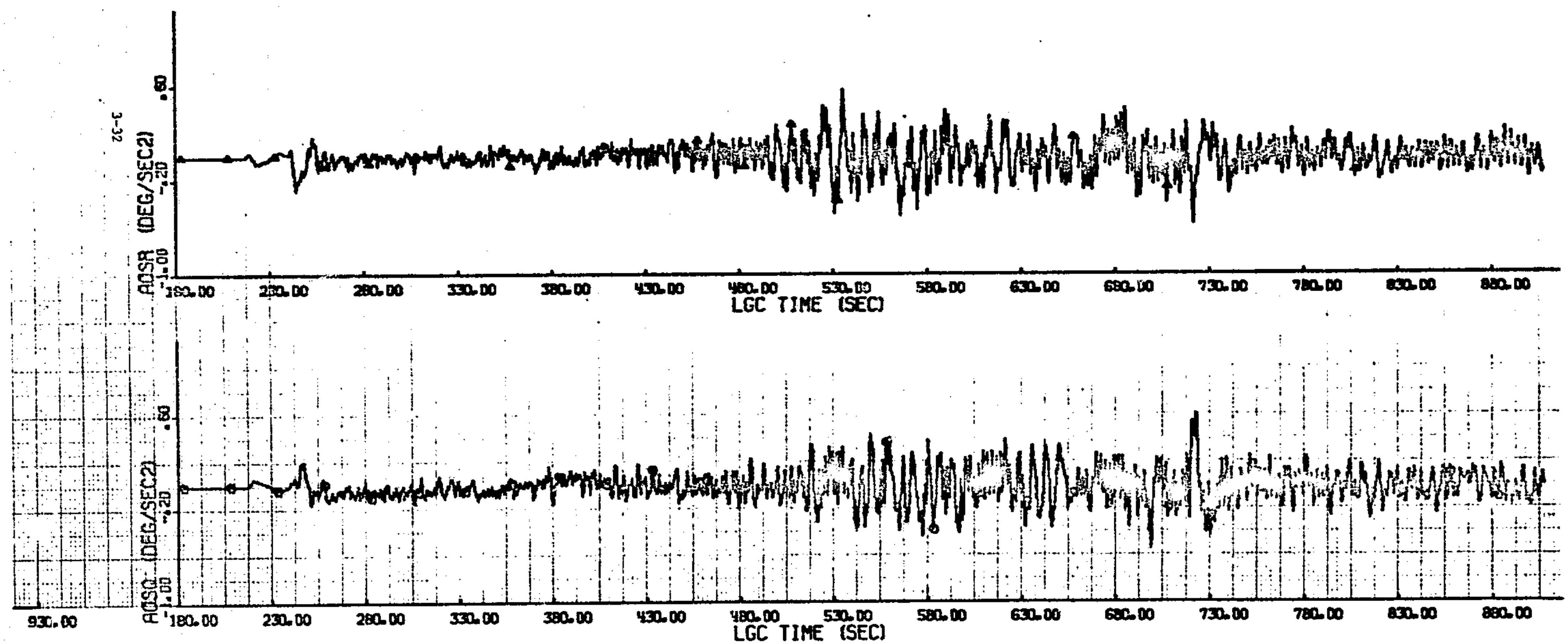
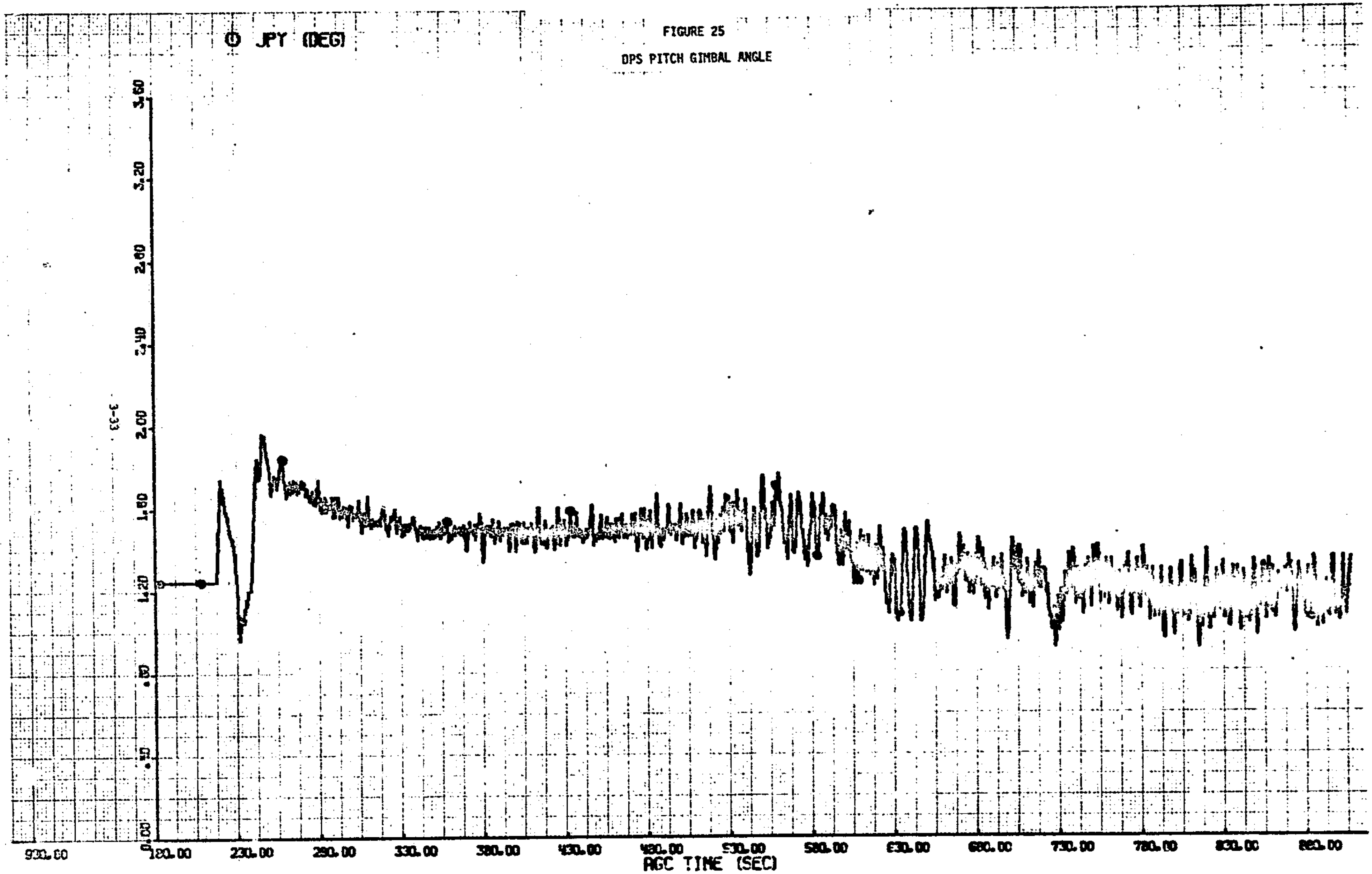


FIGURE 25

DPS PITCH GIMBAL ANGLE



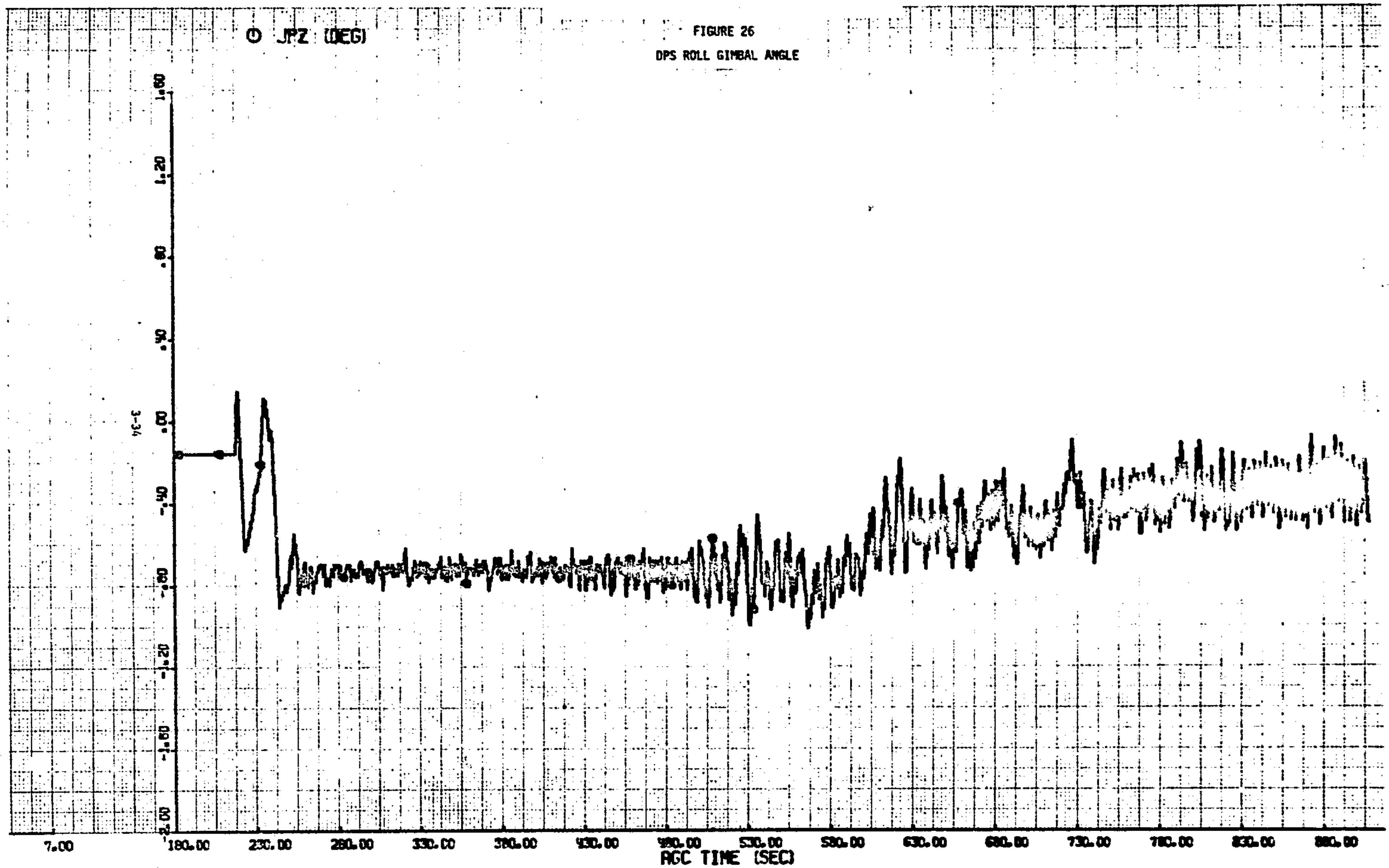


FIGURE 26

DPS ROLL GIMBAL ANGLE

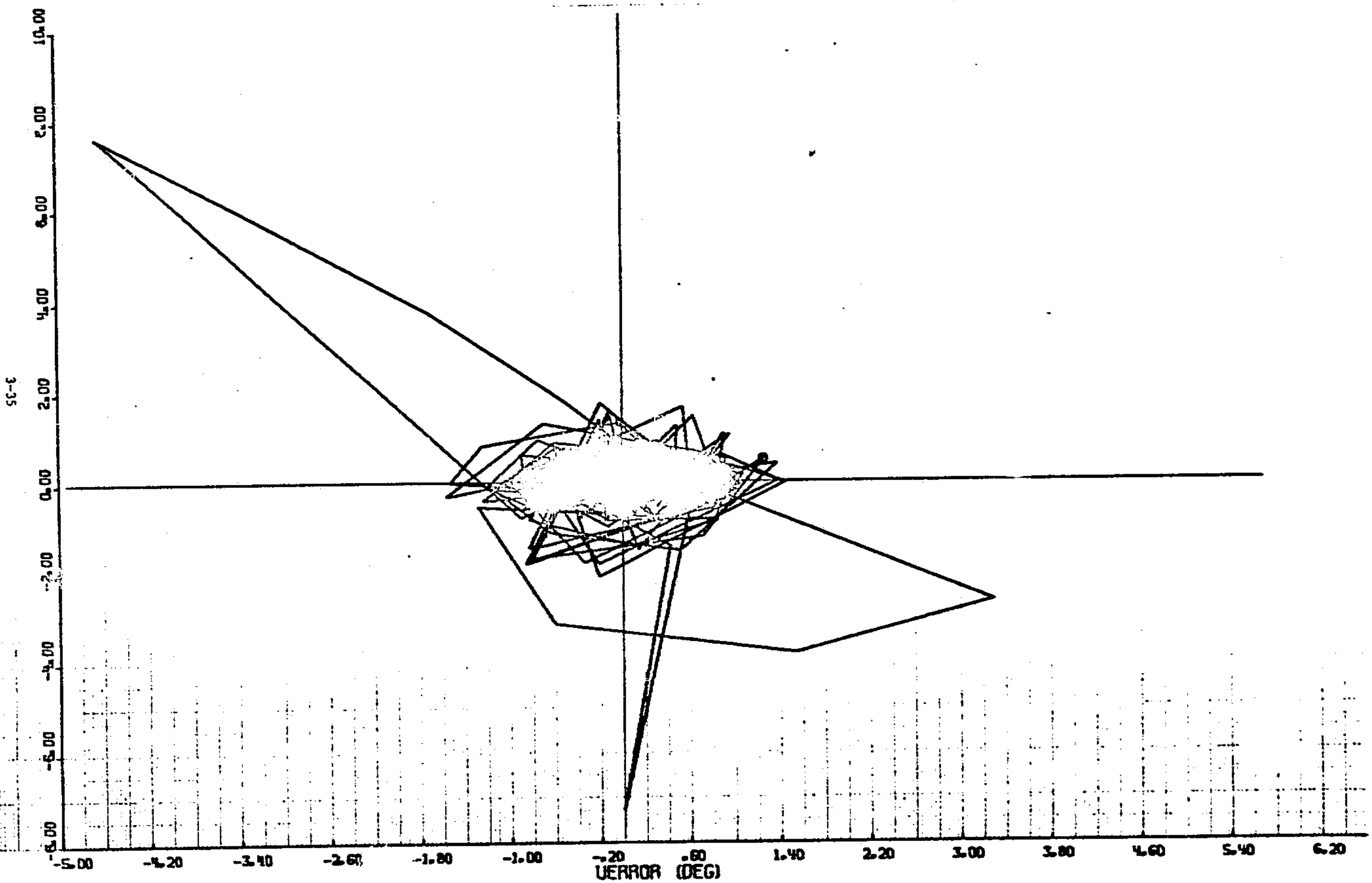


FIGURE 27
U' - AXIS PHASE PLANE

FIGURE 28

V' - AXIS PHASE PLANE

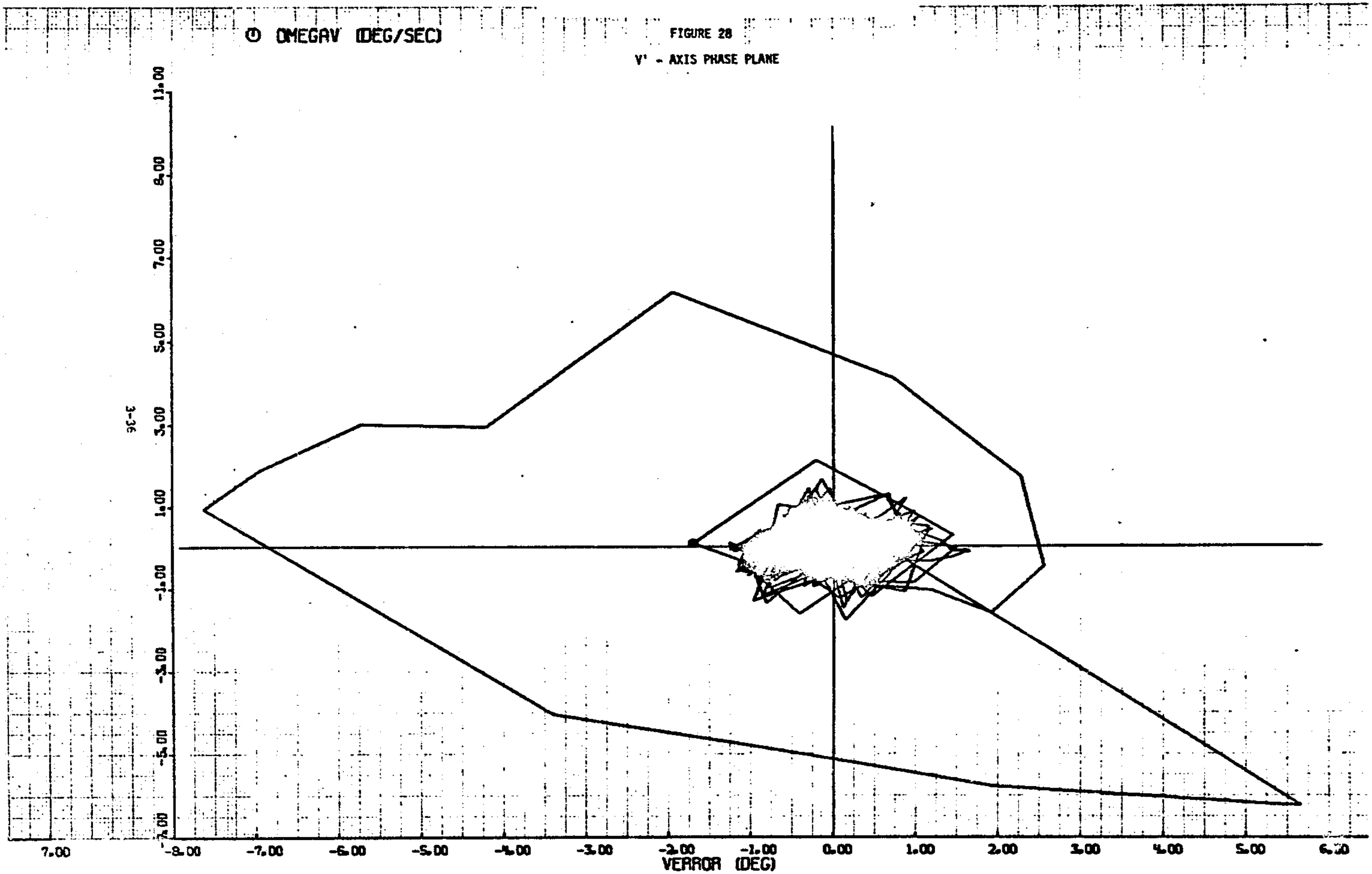


FIGURE 29

THRUST PROFILE

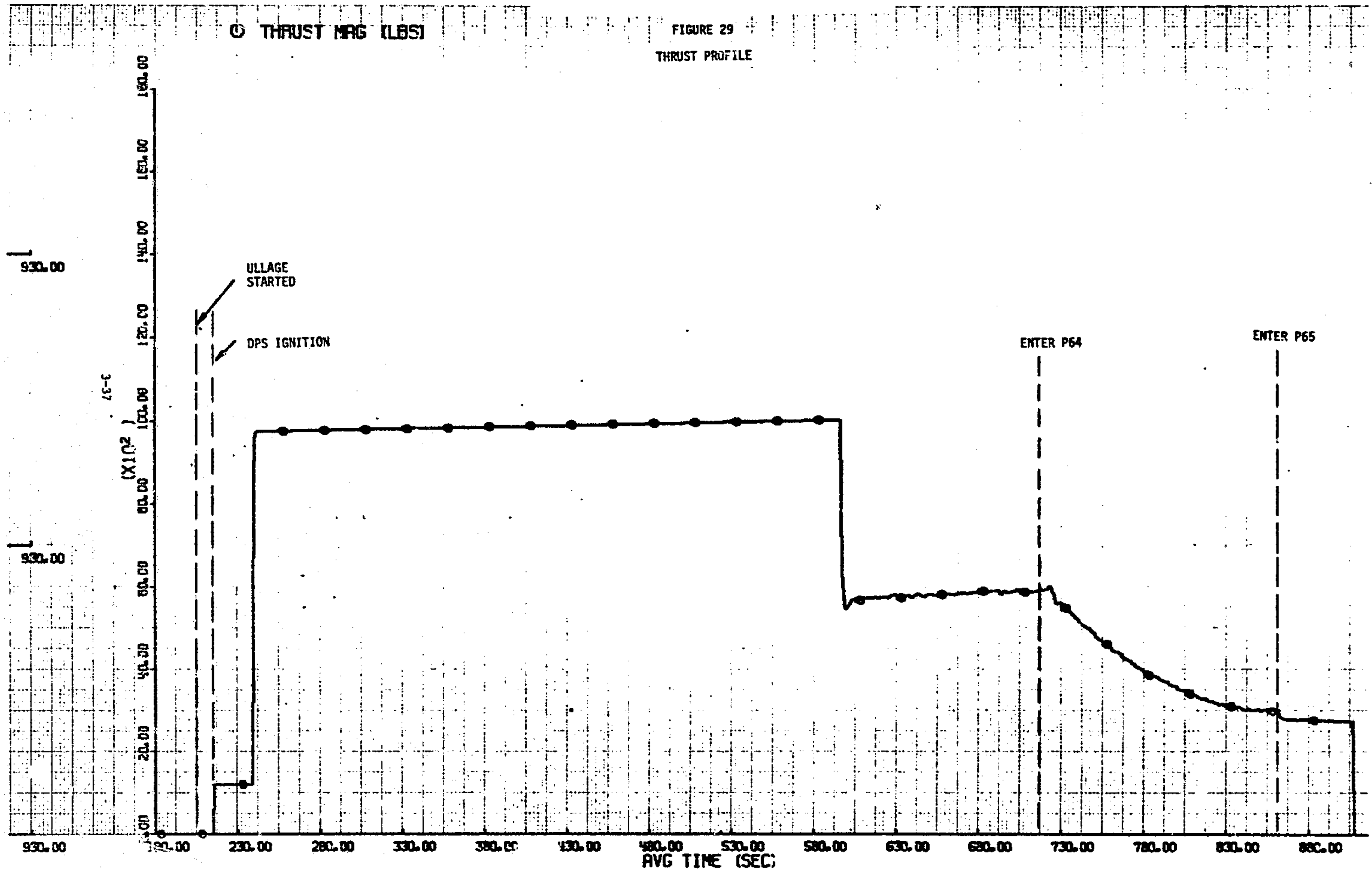


FIGURE 30

RCS ACTIVITY

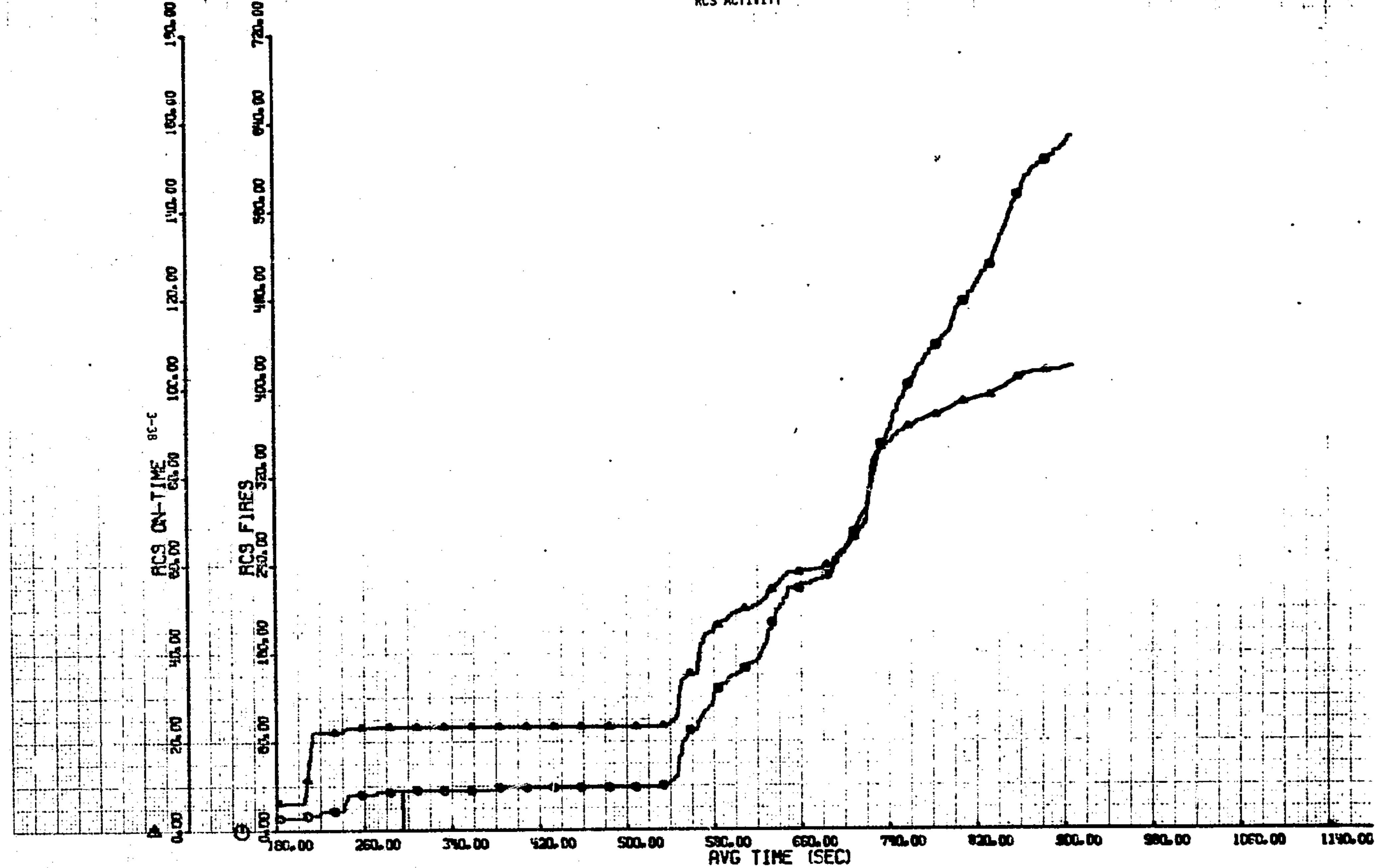


FIGURE 31

PITCH BODY RATES DURING P64 PITCHOVER: ACTUAL AND ESTIMATED

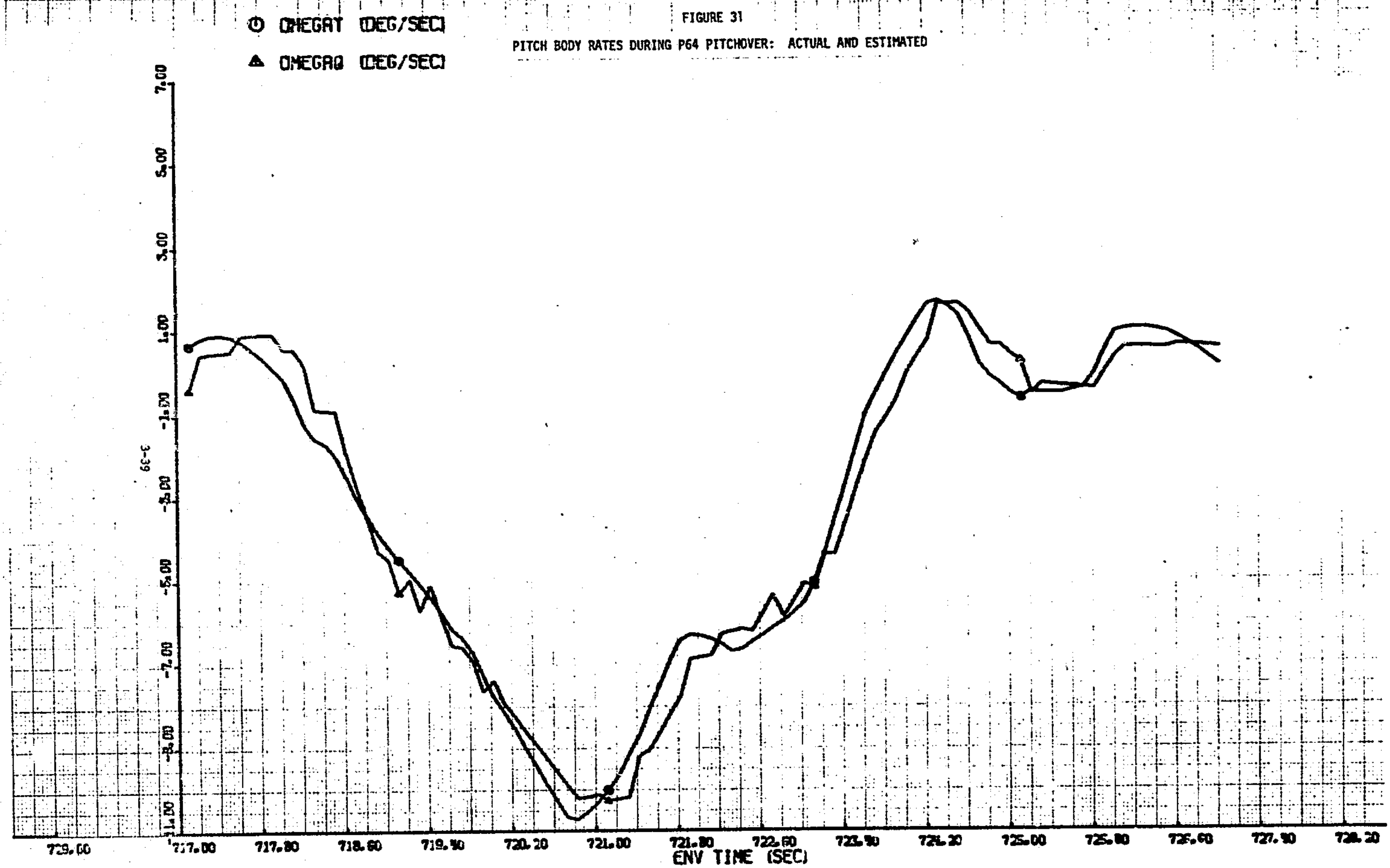
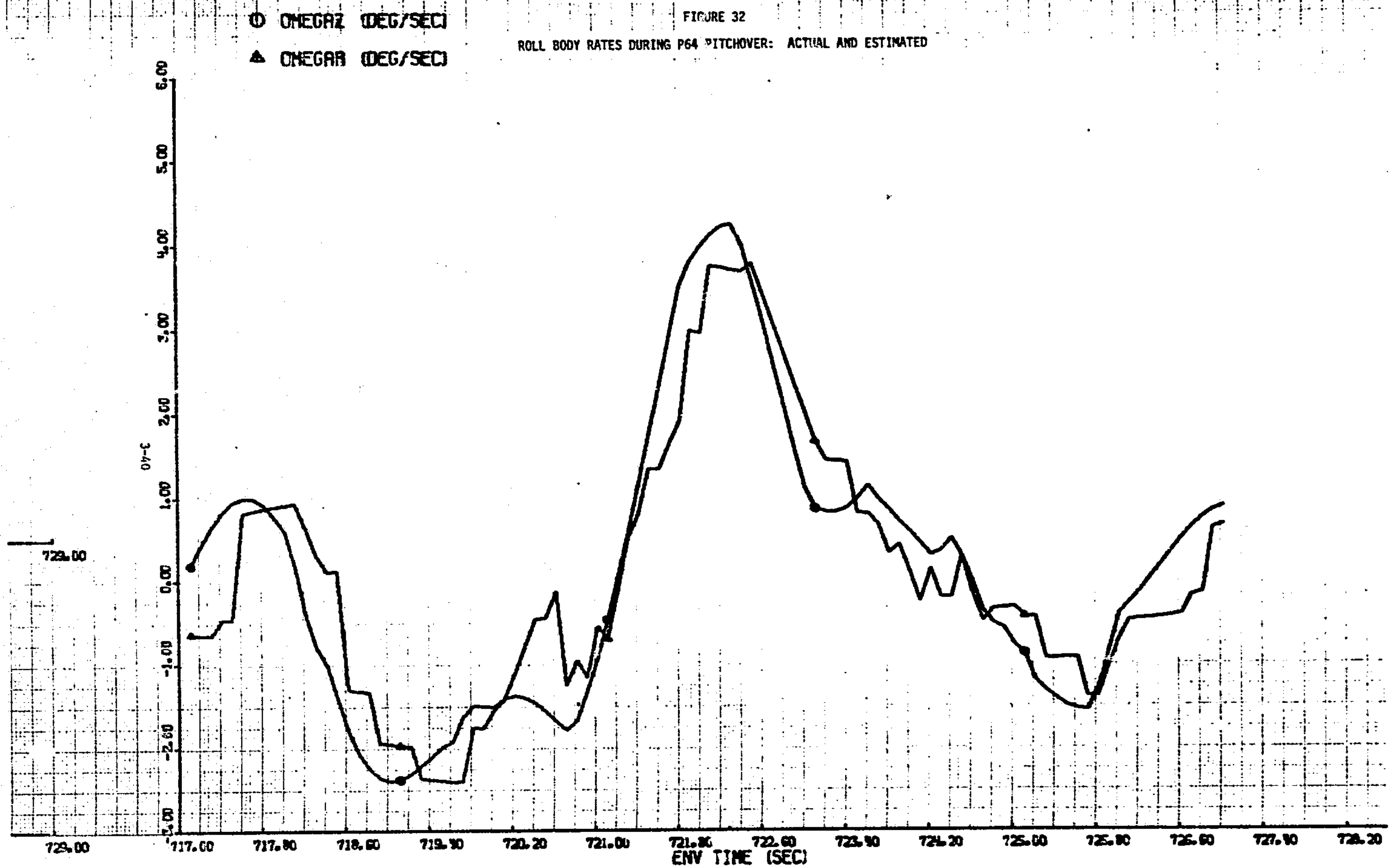


FIGURE 32

ROLL BODY RATES DURING P64 PITCHOVER: ACTUAL AND ESTIMATED



3.3 LANDING SEQUENCE WITH RHC LATERAL REDESIGNATIONS, Run H1-1.3

Test Description

Automatic landing including a three click lateral redesignation via RHC in P64. DOI has been completed and LM is in proper descent orbit at the beginning of the test.

Test Objective

Evaluate the DAP performance during a descent sequence in which a three click lateral redesignation is performed during P64.

Initialization Data

This run started from a checkpoint restart in the nominal descent run and thus had the same initialization as run H1-1.0.

Timeline

The following is a list of the major events and their times of occurrence.

	Time-Seconds	Event
1)	205.0575	Ullage initiated
2)	212.5605	DPS engine ignition command
3)	213.0565	Ullage completed
4)	717.0752	Enter Visibility Phase Program, P64
5)	782.56	Entered first click redesignation
6)	786.56	Entered second click redesignation
7)	790.56	Entered third click redesignation
8)	859.2903	Enter Automatic Landing Program, P65
9)	888.5563	LM stop button
10)	889.1393	DPS engine off
11)	889.5564	Touchdown confirmed

The total time between ignition and lunar touchdown was 676.99 seconds or about 11.3 minutes. The plots presented in Figures 33 through 46 consider only the time interval from the latter portion of the pitch-over maneuver in P64 to lunar touchdown.

Results

Figures 33 through 46 are plots of the various LGC and Environmental parameters pertinent to this test case. Table 1 indicates the magnitudes and times of occurrence of certain key variables. Table 2 presents a summary of the RCS activity. Data for Figures 33 through 46 were obtained every fifth DAP cycle or 0.5 second.

The three redesignations were entered by the simulated astronaut at four-second intervals about midway in P64. Figure 38 shows that the transient due to the first redesignation had just about died out when the second redesignation was entered. The same was true for the third. The peak angular rates for the yaw and roll axes during the redesignation were 2.20 and 1.75 deg/sec, respectively. The DAP performed well in maintaining the specified deadband with respect to attitude and rate errors about the control axes. Very little, if any, overshoot was obtained in angular rates and attitude at the completion of the redesignation.

Slosh was not excessively excited by the redesignations. The only noticeable buildup was in the yaw axis where the slosh rate amplitude went from a peak-to-peak amplitude at 0.15 degree per second before the redesignations to 0.35 deg/sec afterwards. The slosh amplitudes in the other two spacecraft axes remained about constant.

The total angular redesignation obtained in this run turned out to be about 7.4 degrees. This averages out to be about 2.5 degrees per click. This is slightly high since the expected angular deviation caused by a lateral redesignation is approximately 2.0 degrees per click. The above numbers were calculated from the spacecraft position vector at the time the first redesignation was entered, the position vector of the actual landing site, and the position vector of the nominal landing site. The three position vectors in inertial reference system are as follows:

At Time of Redesignation	At Landing Site	Nominal Landing Site
$\begin{bmatrix} 1373945.8 \\ 977984.737 \\ 412933.644 \end{bmatrix}$ m	$\begin{bmatrix} 1374318.451 \\ 976925.517 \\ 412637.122 \end{bmatrix}$ m	$\begin{bmatrix} 1374344.024 \\ 976953.210 \\ 412486.520 \end{bmatrix}$ m

The preceding calculation of the redesignation angle is not exact inasmuch as it was assumed that all of the redesignations occurred at the same time. In the actual simulation, the redesignations were separated by four-second time intervals. The DAP performance was satisfactory throughout this simulation. The guidance commands were executed properly and the DAP maintained good attitude control throughout the period of redesignation.

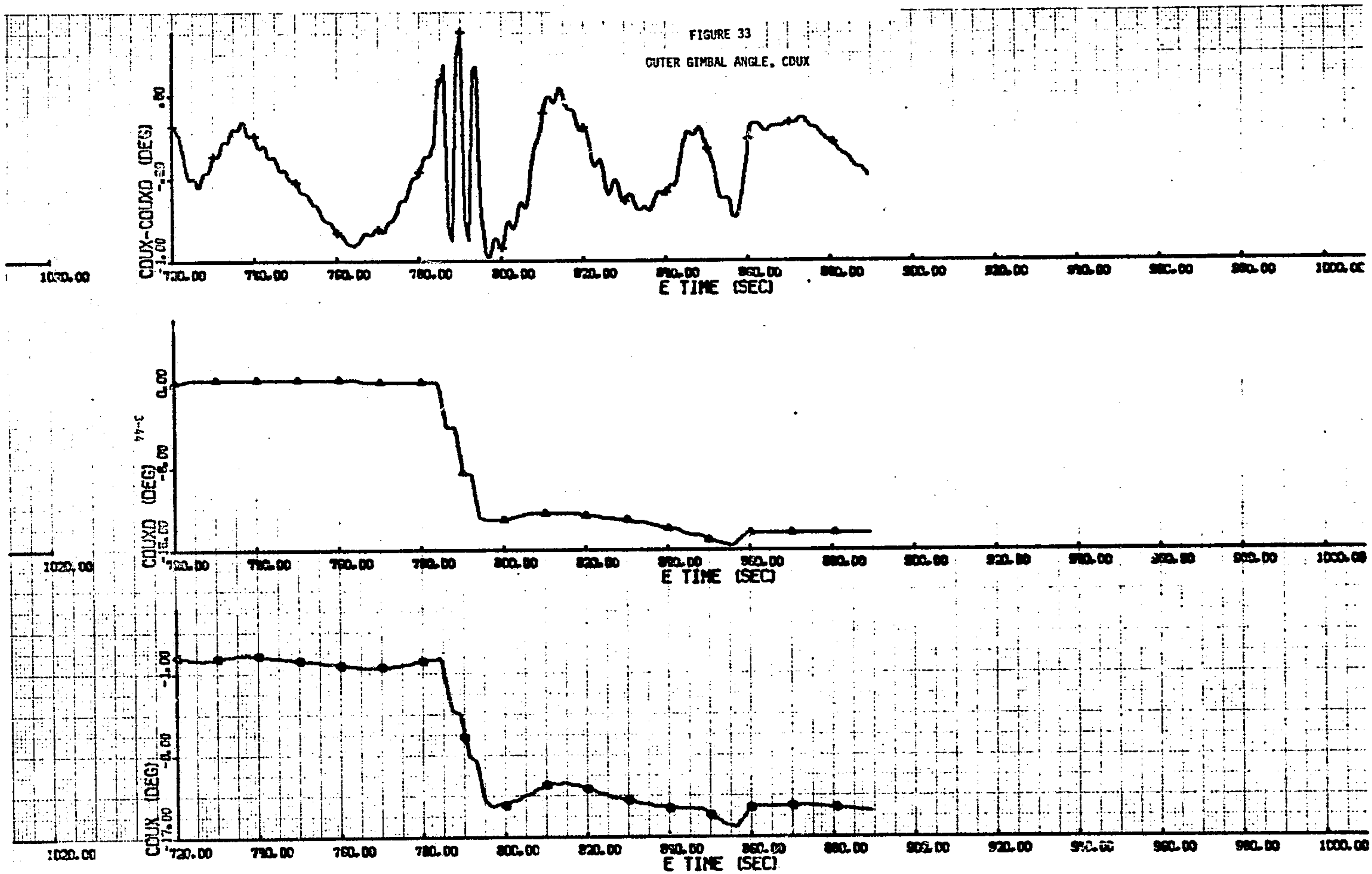


FIGURE 33

OUTER GIMBAL ANGLE, CDUX

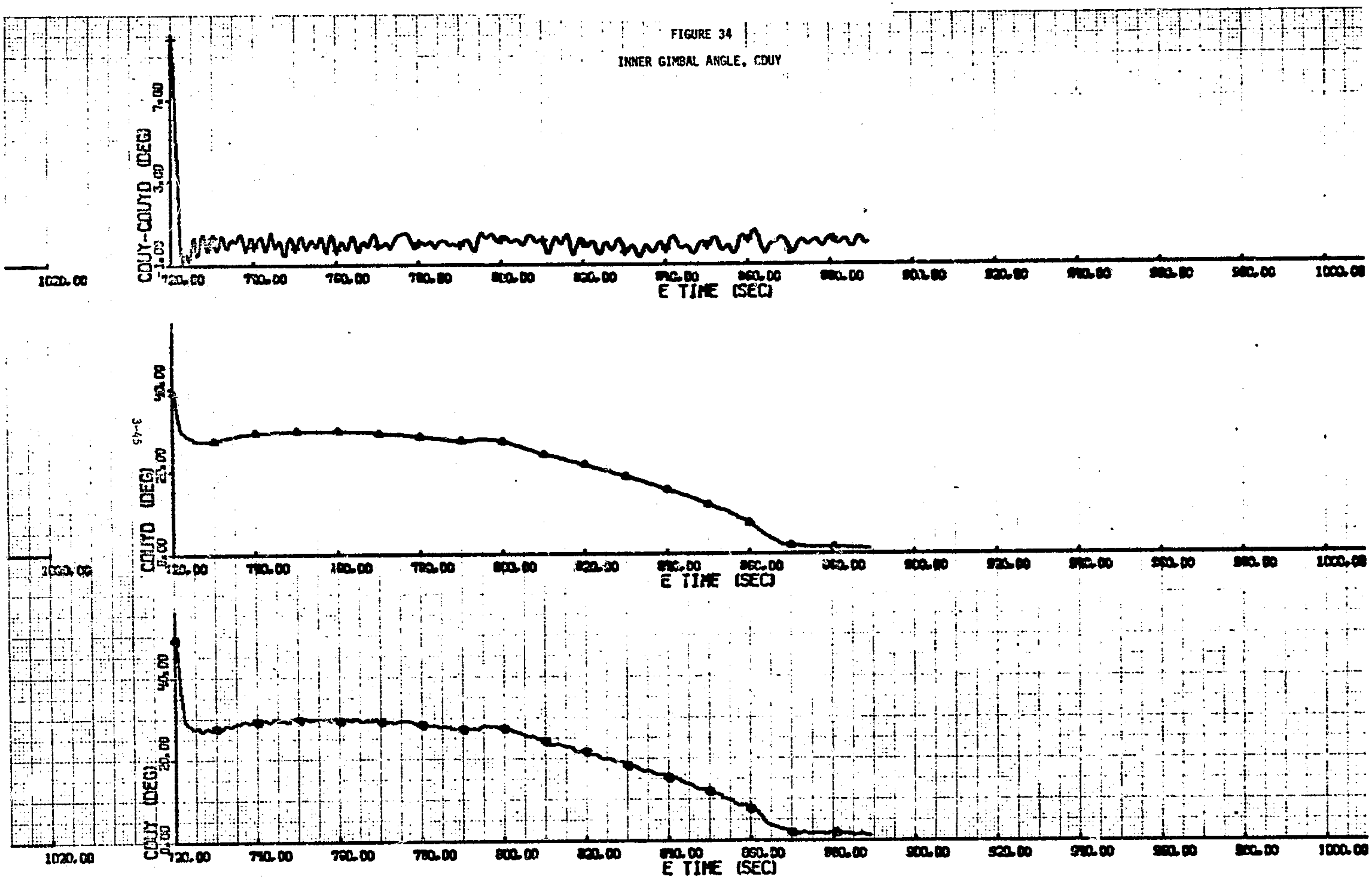


FIGURE 34

INNER GIMBAL ANGLE, CDUY

FIGURE 35

MIDDLE GIMBAL ANGLE, CDUZ

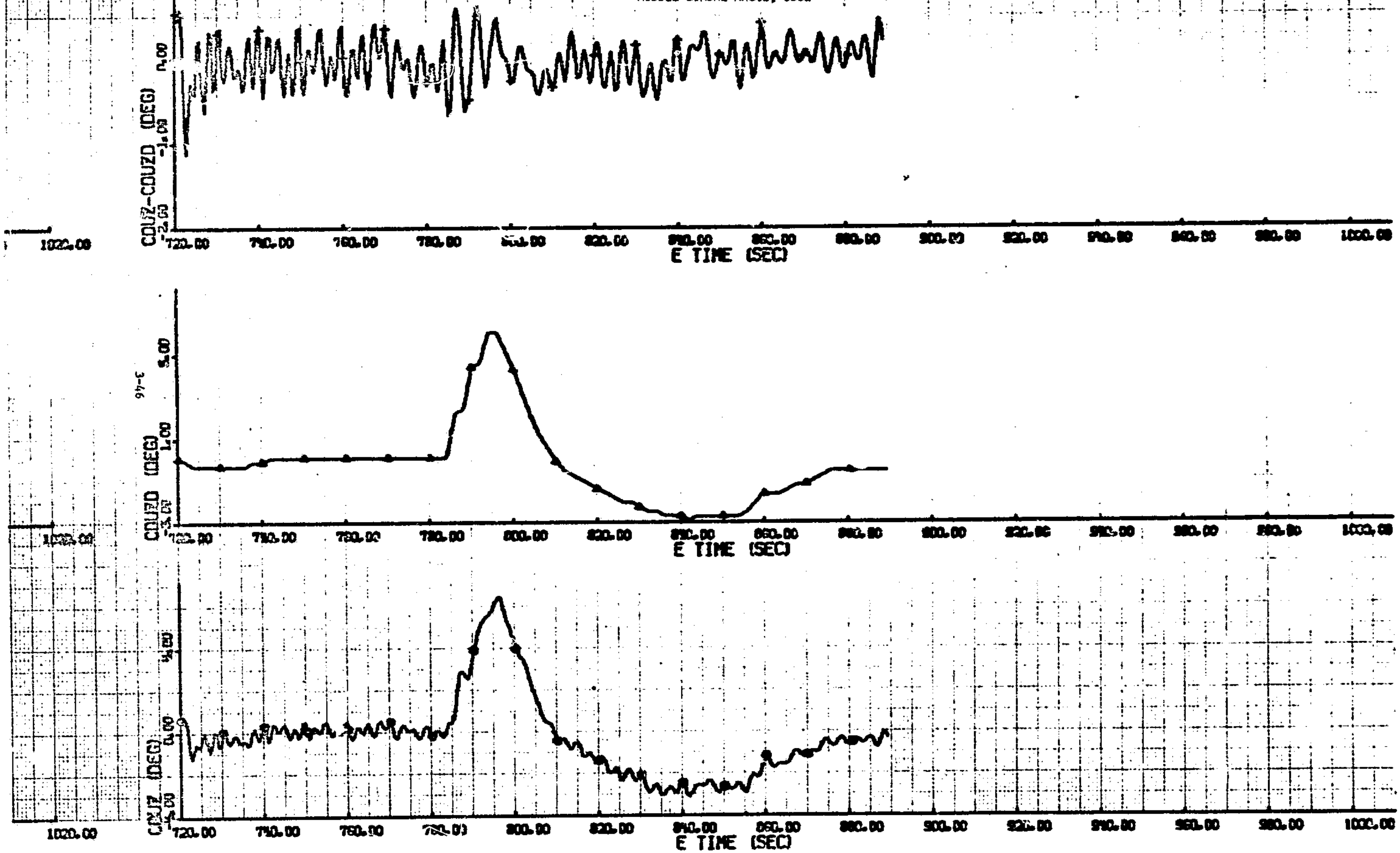


FIGURE 36

PITCH, YAW, AND ROLL ATTITUDE ERRORS

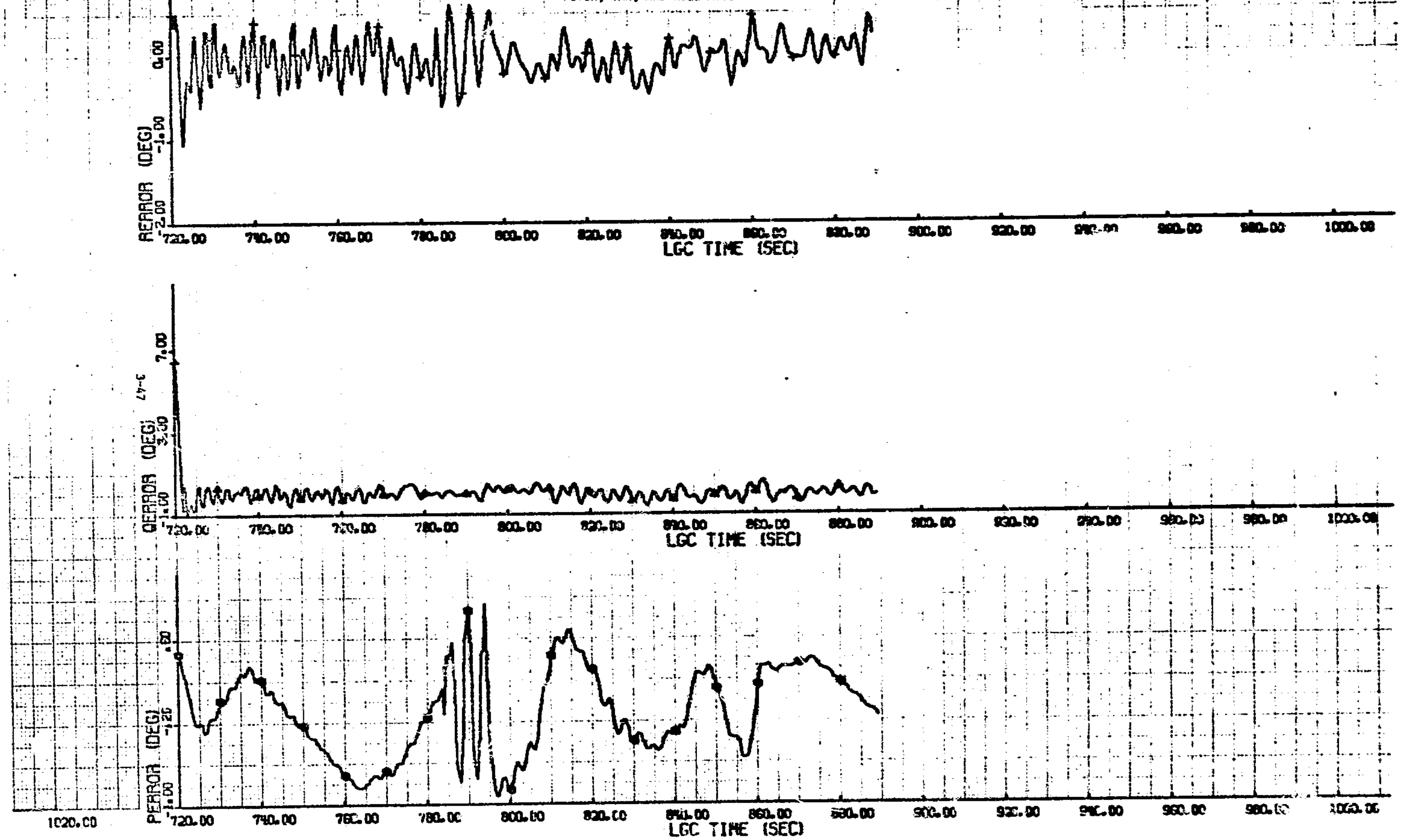


FIGURE 37

U', V' CONTROL AXES ATTITUDE ERRORS

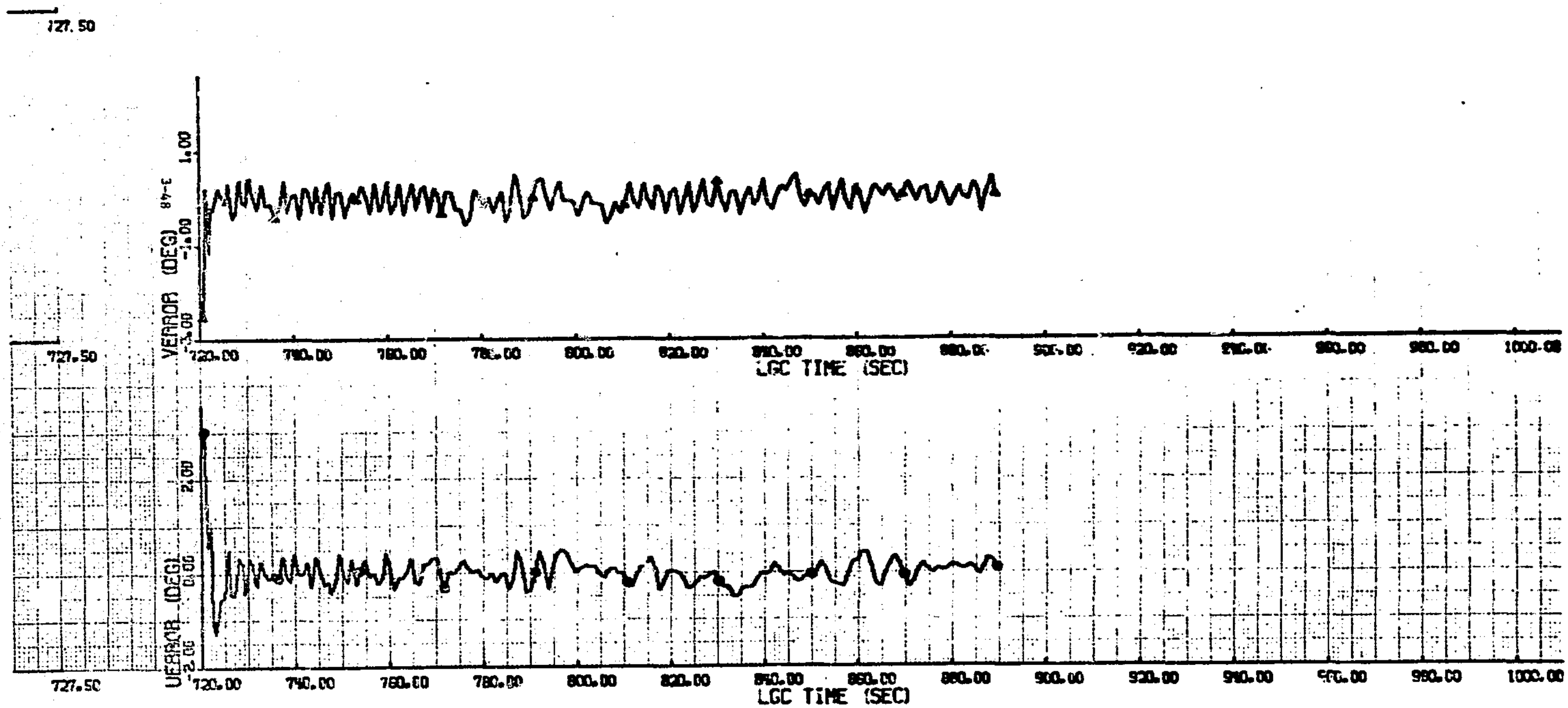
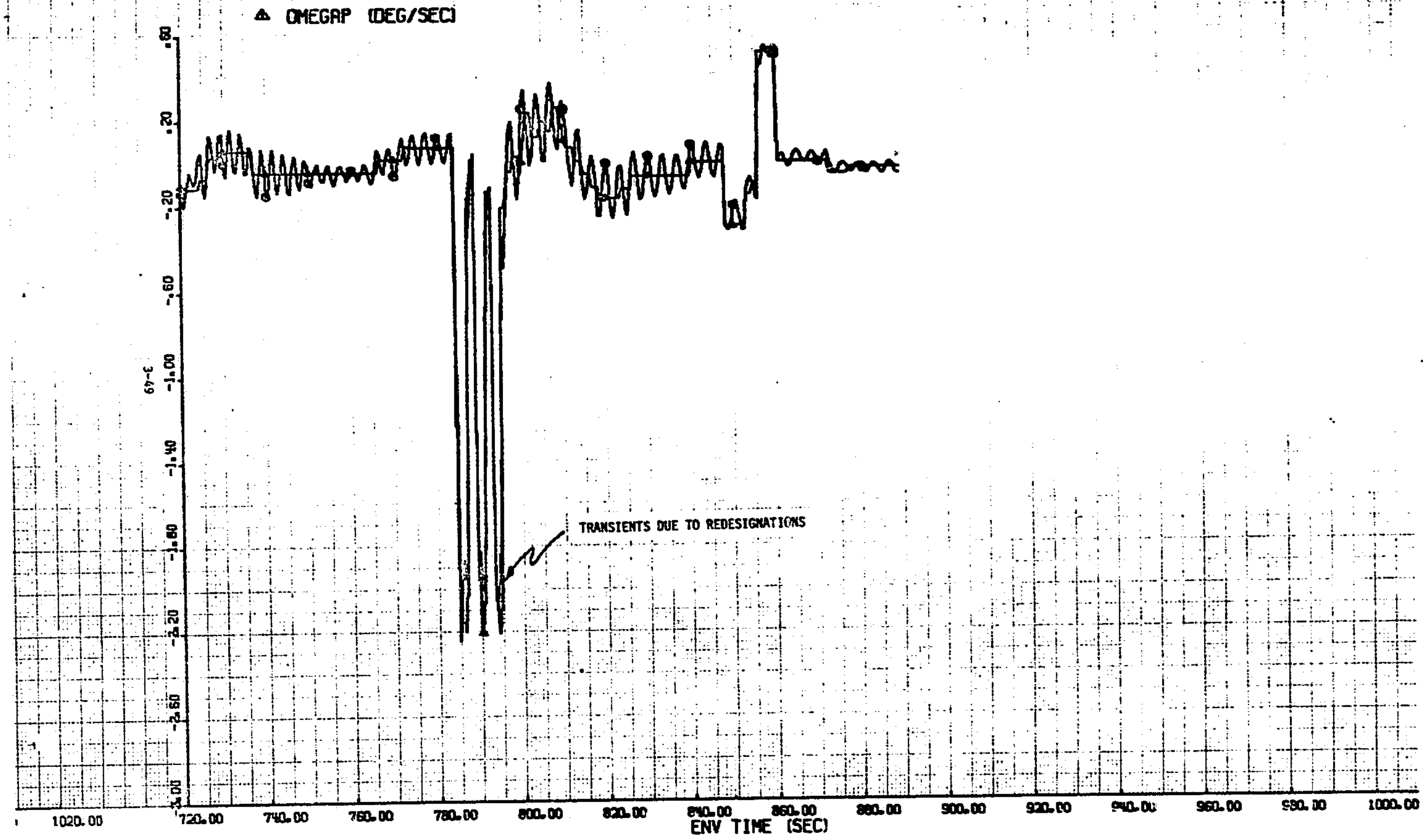


FIGURE 38

YAW BODY RATES: ACTUAL AND ESTIMATED



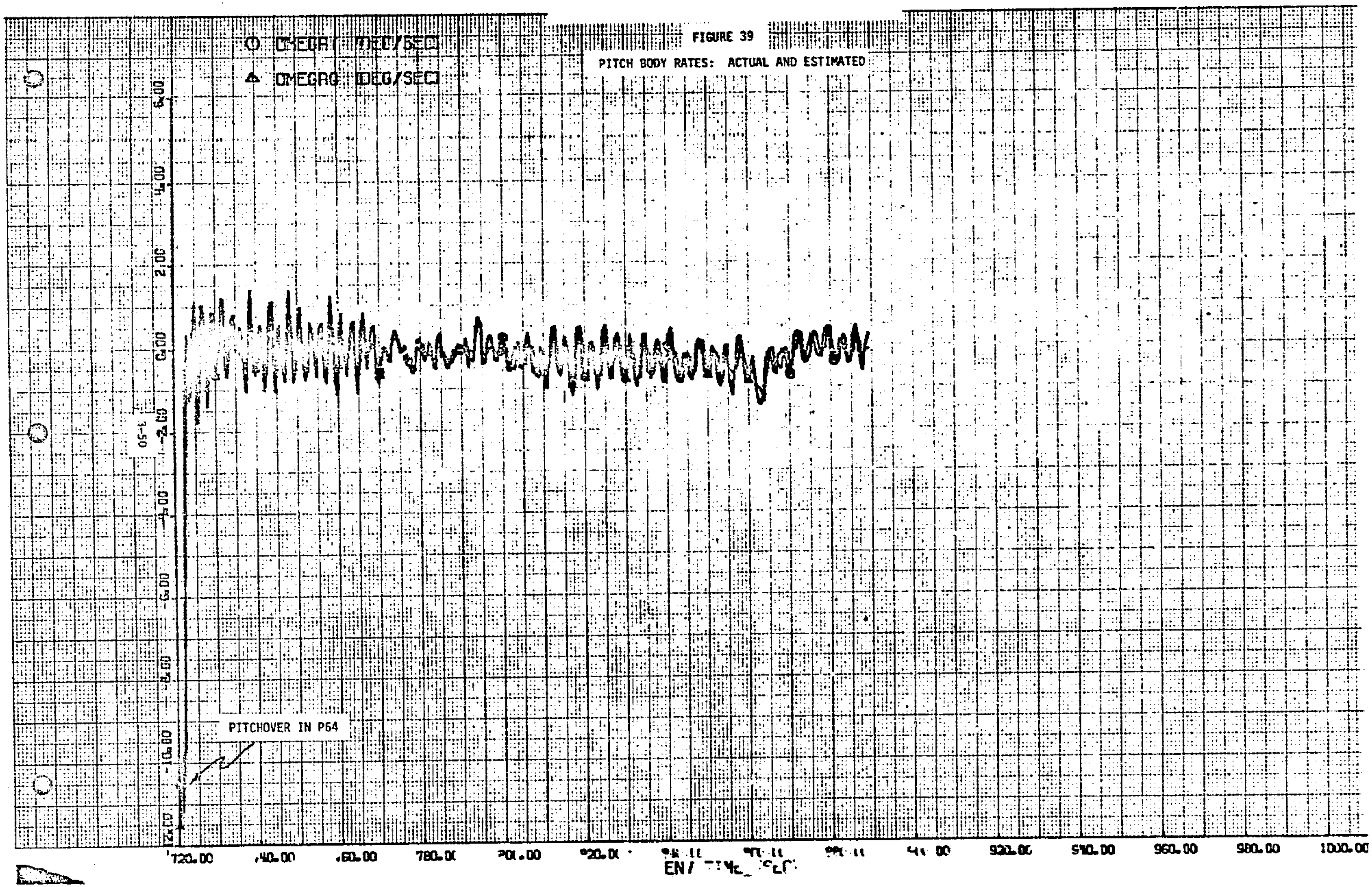


FIGURE 39

PITCH BODY RATES: ACTUAL AND ESTIMATED

FIGURE 40

ROLL BODY RATES: ACTUAL AND ESTIMATED

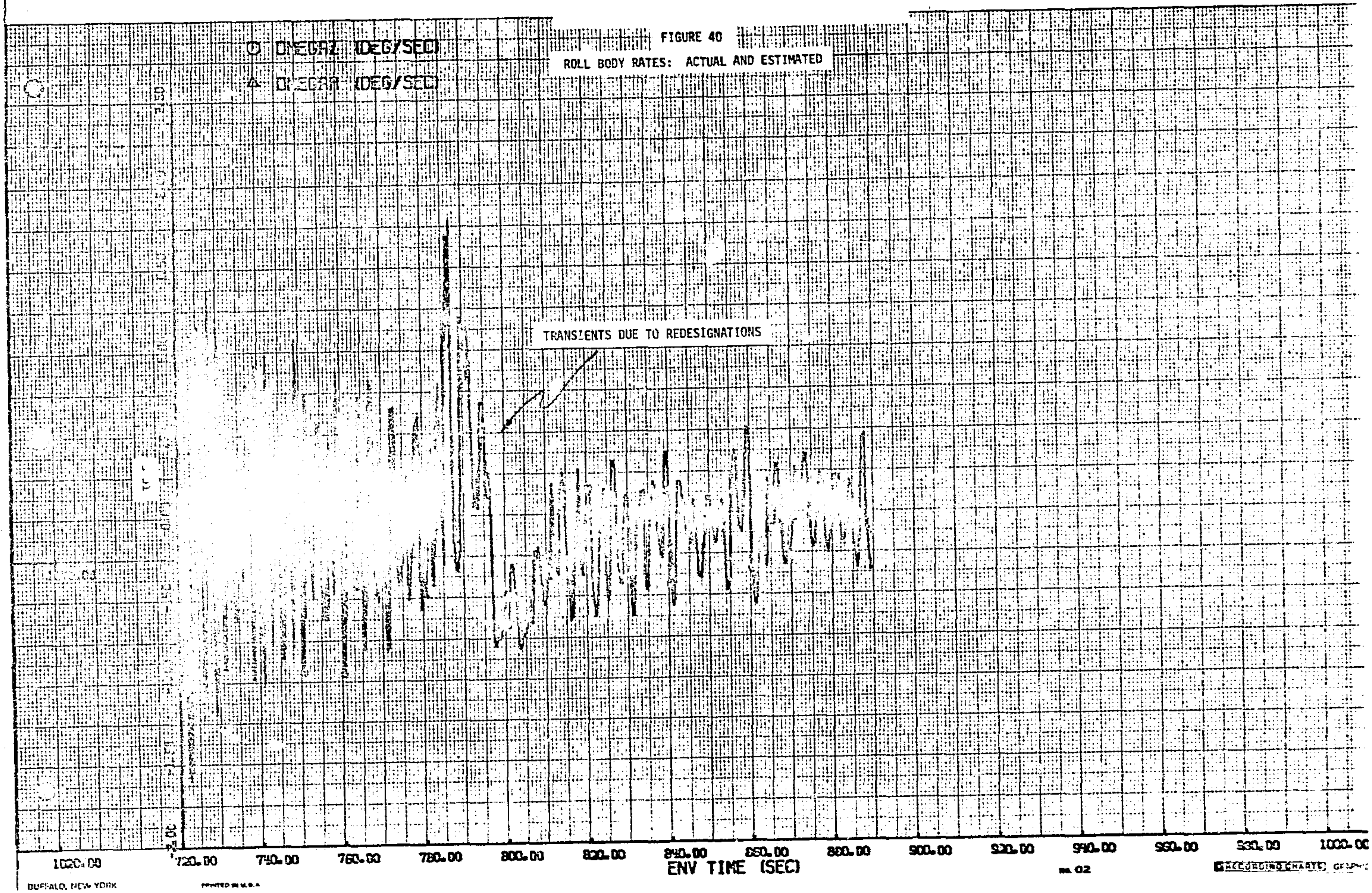


FIGURE 41

RATE ERRORS: U', V' - AXES

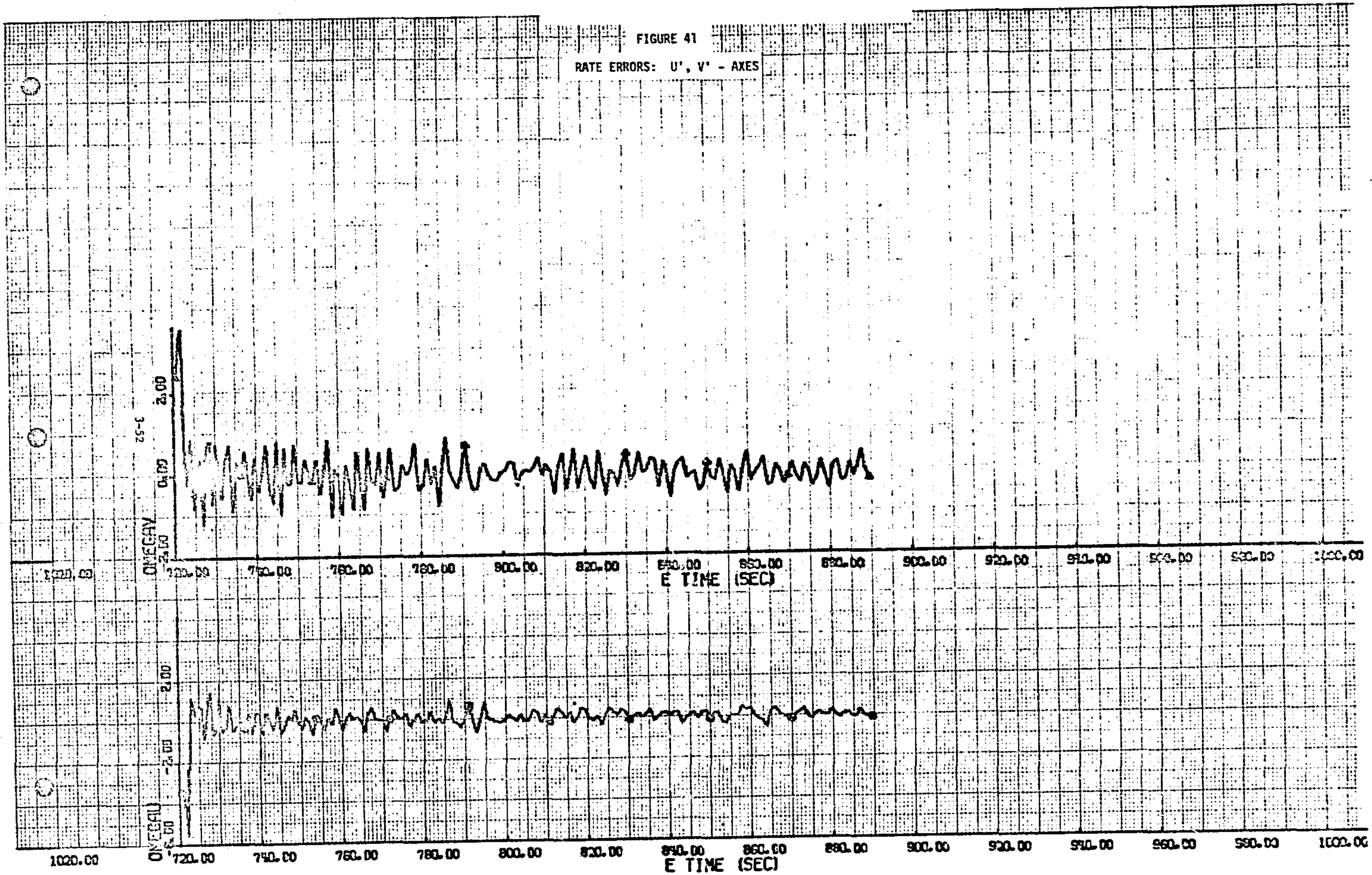


FIGURE 42

ESTIMATED BODY OFFSET ACCELERATIONS

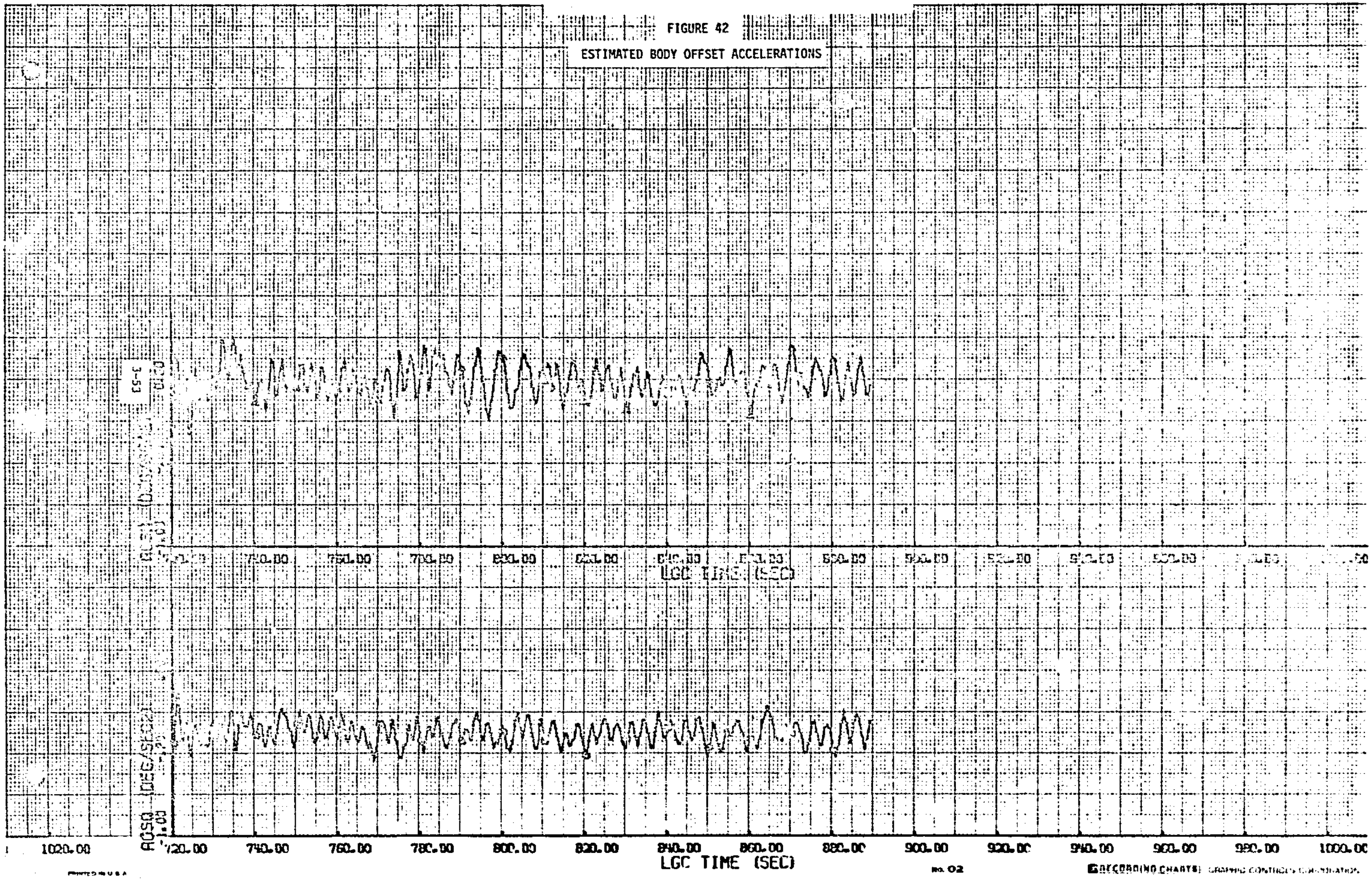
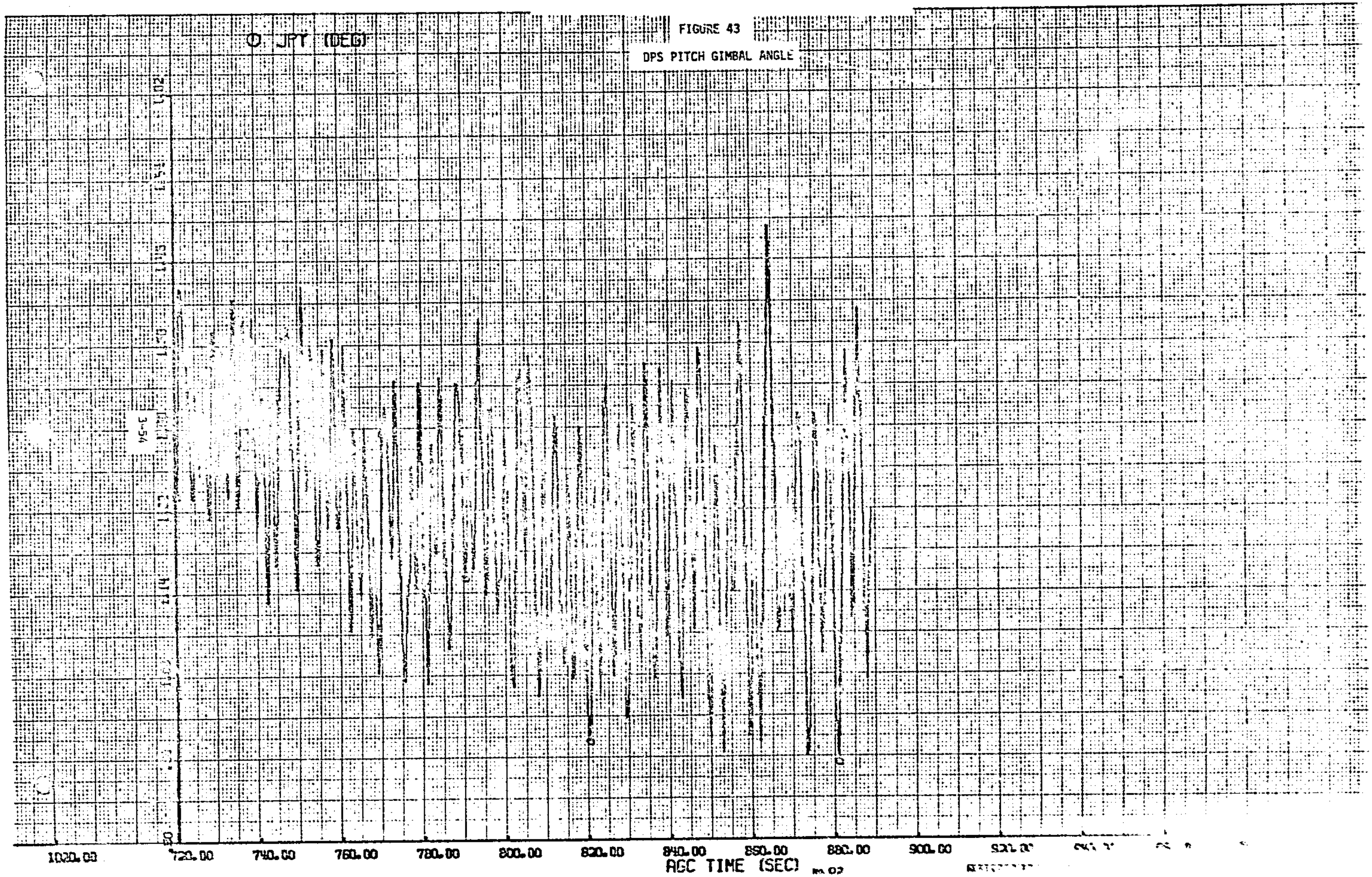


FIGURE 43

DPS PITCH GIMBAL ANGLE



3-54

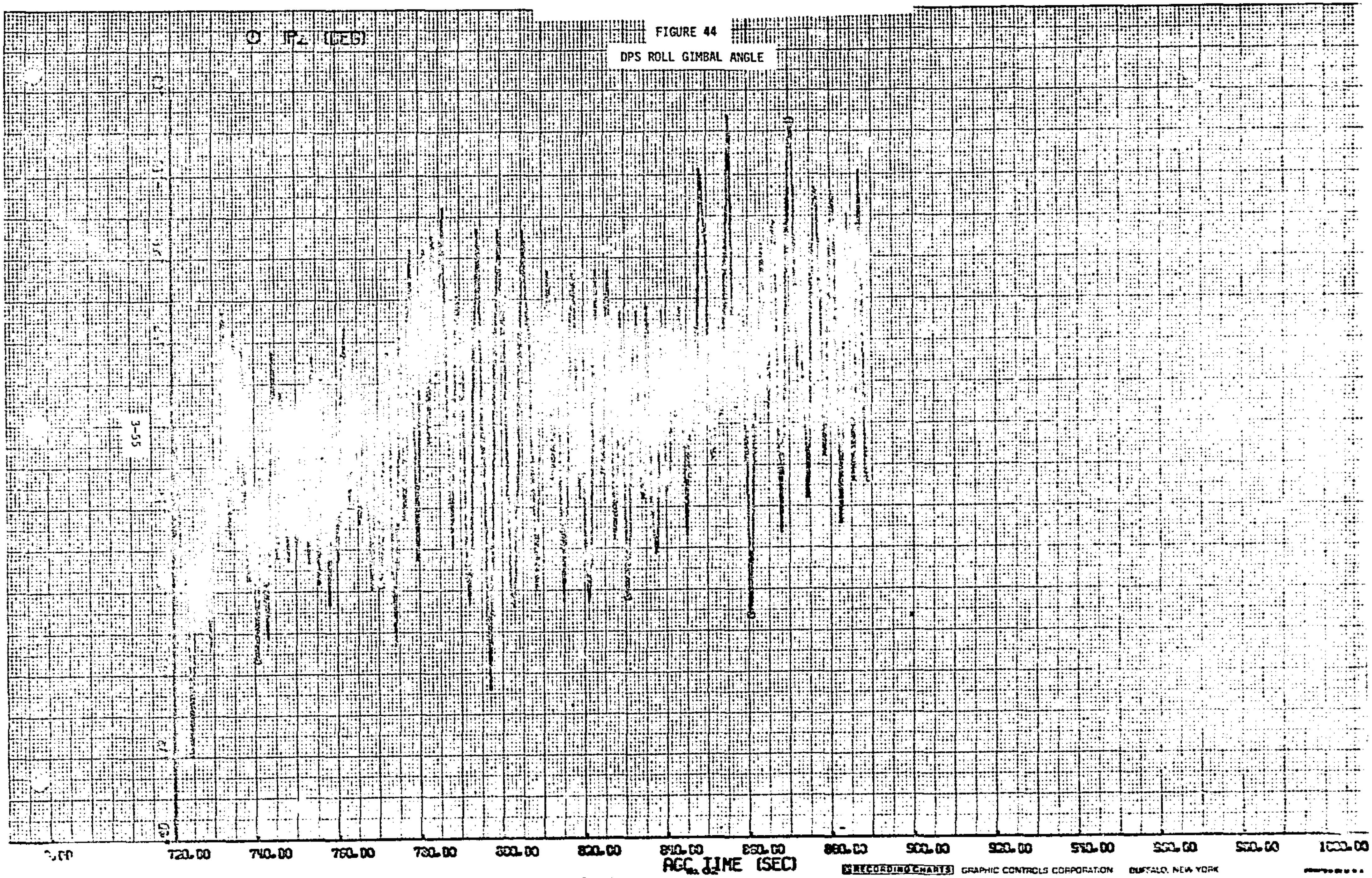


FIGURE 44

DPS ROLL GIMBAL ANGLE

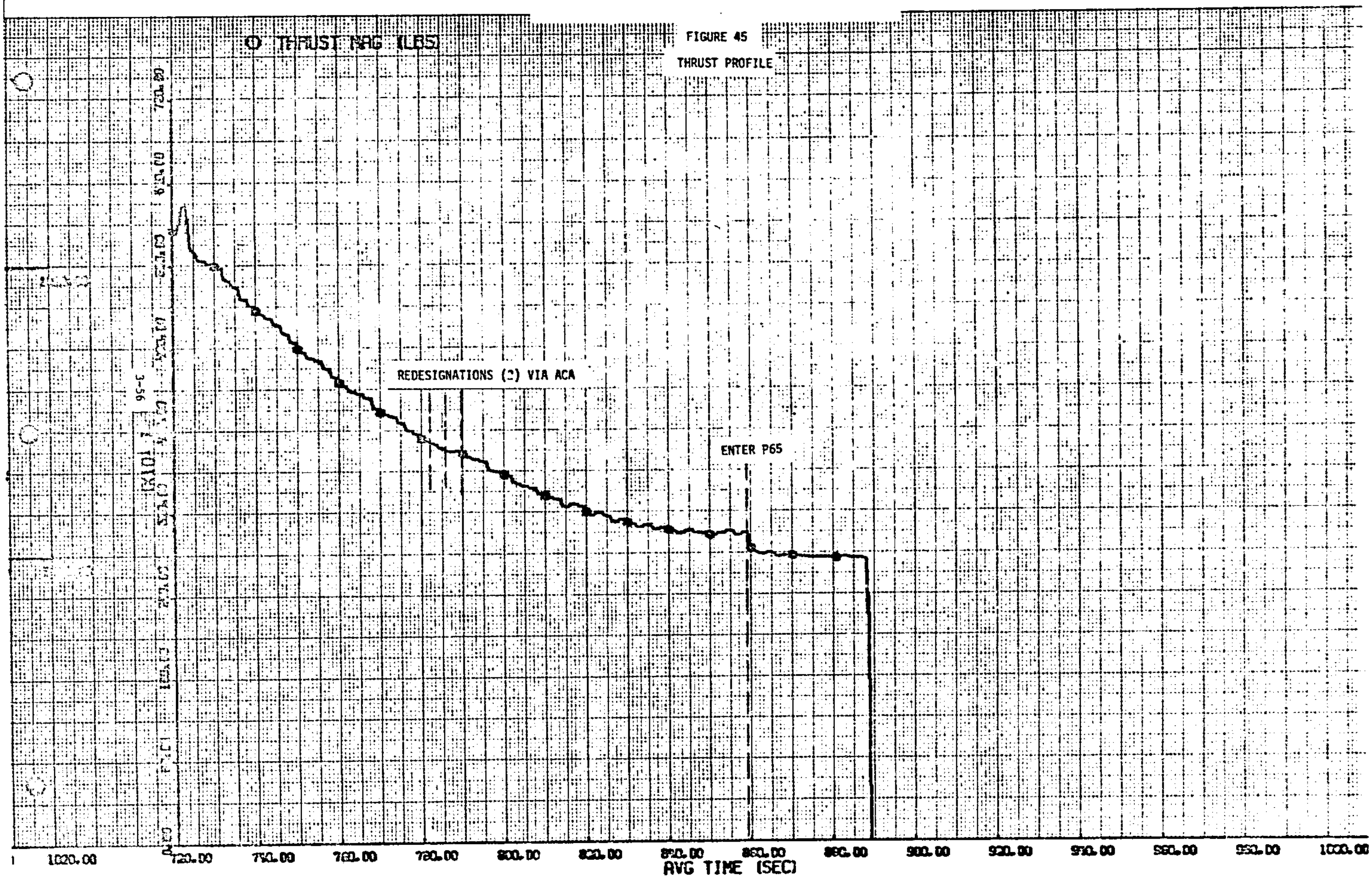


FIGURE 45
THRUST PROFILE

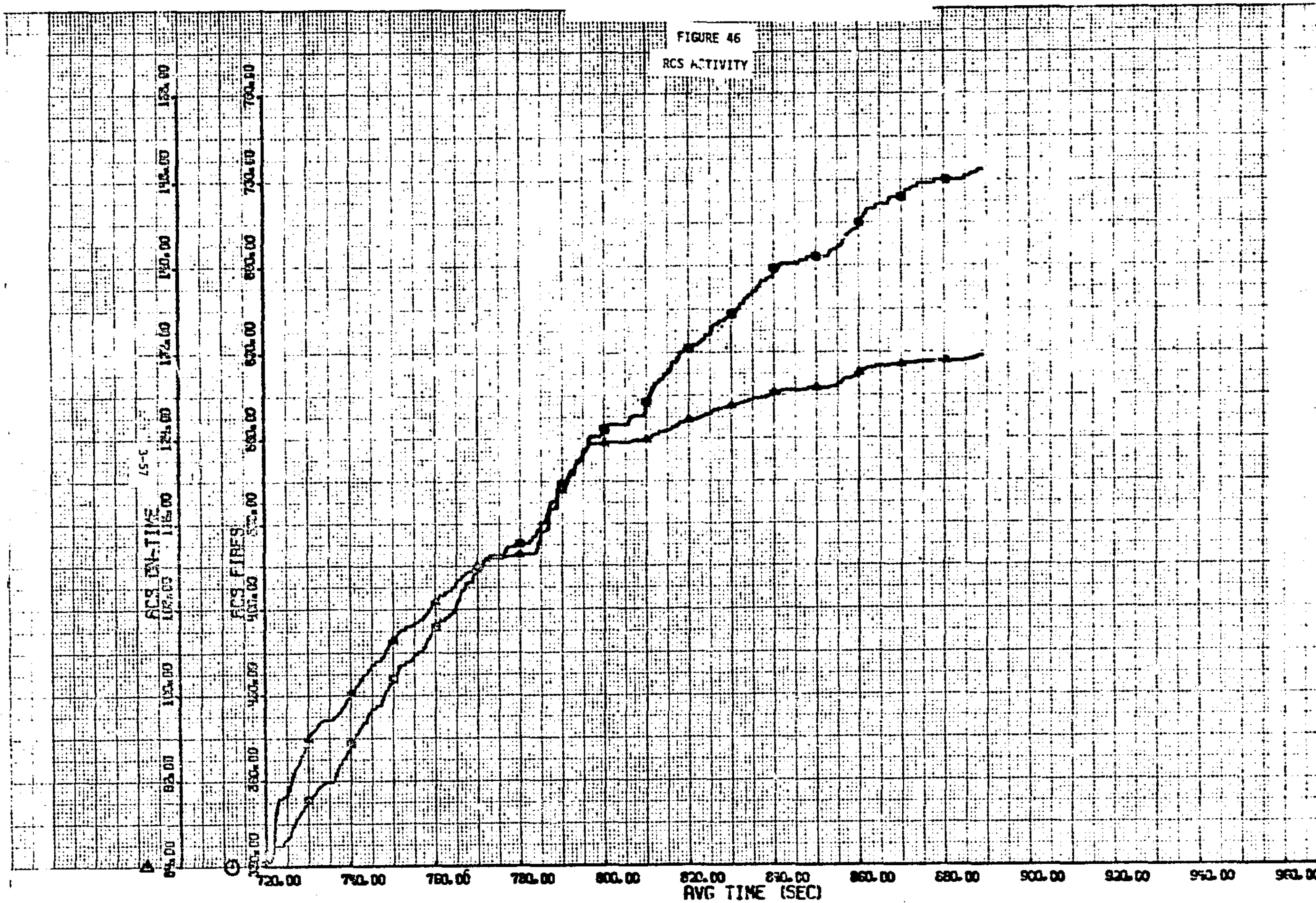


FIGURE 46
RCS ACTIVITY
RCS ON-TIME
RCS FIRES
AVG TIME (SEC)
720.00
740.00
760.00
780.00
800.00
820.00
840.00
860.00
880.00
900.00
920.00
940.00
960.00

3.4 DESCENT WITH ΔRLS REDESIGNATION PRIOR TO IGNITION, RUN H1-1.4

Test Description

Automatic landing including a 10,000 ft downrange redesignation via N69 (ΔRLS method) prior to the start of the ignition algorithm. Descent Orbit Injection has been completed and LM is in proper descent orbit at the beginning of the test.

Test Objective

Evaluate the DAP performance during a descent sequence in which a downrange redesignation is performed prior to ignition.

Initialization Data

The initialization data for this test case are the same as for the nominal descent run, Run H1-1.0.

Timeline

The following is a list of the major events and their times of occurrence.

	Time-Seconds	Event
1)	49.980	Enter redesignation (N69)
2)	206.8664	Ullage Started
3)	214.3705	DPS Engine Ignition Command
4)	214.8664	Ullage completed

Results

The simulation for this run was terminated shortly after ignition and a complete landing was not attempted. A redesignation via N69 prior to the initiation of the ignition algorithm merely delays the ignition time an appropriate amount of time in order to achieve the specified downrange distance. The trajectory flown would be the same as in the nominal case except, it would be displaced downrange relative to the nominal landing site. The DAP performance for this run is exactly the same as the nominal run and thus no plots were included in order to prevent duplication.

The timeline indicates that the ignition signal for this run came 1.81 seconds later than it would have been, had there been no redesignation. Using this delay and the spacecraft velocity vector that existed at ignition, the calculated downrange displacement of the landing site was 10,069 ft.

This is only 0.69% greater than the specified distance of 10,000 ft. The V69 method of redesignation is considered satisfactory based on the results of this simulation.

TABLE 1

KEY VARIABLES

Description	Variable	Run Number		
		H1 - 1.0	H1 - 1.2	H1 - 1.3**
Maximum Attitude Errors (deg) (Time of Occurrence - sec)	PERROR	-6.25 (546.25)	-7.25 (547.)	0.92 (794.)
	QERROR	-6.25 (718)	8.0 (720.)	-0.40 (795.)
	RERROR	1.55 (672.5)	-4.3 (722)	-0.64 (785.)
	UERROR	3.0 (720)	-4.6 (718.)	0.50 (787.)
	VERROR	4.0 (717.5)	-7.75 (720.)	0.50 (787.)
Maximum Rates (deg/sec) (Time of Occurrence - sec)	OMEGAP	-10.7 (550.)	-10.5 (555.)	-2.2 (785.)
	OMEGAQ	-11.5 (720.)	-10.7 (722.)	-0.5 (784.)
	OMEGAR	-1.9 (692.5)	4.2 (722.5)	1.75 (787.)
	OMEGAU	7.25 (717.5)	7.9 (718.)	0.9 (786.)
	OMEGAV	-7.25 (717.5)	-6.25 (718.)	0.85 (786.)
Average Peak-to-Peak Attitude Errors (deg)	QERROR	3.0*	3.2*	0.8
	RERROR	3.0*	3.0*	1.2
	UERROR	2.0	2.0	0.9
	VERROR	2.0	2.0	1.0

*The above values were taken at peak amplitudes and were not necessarily sustained oscillations.

**Entries in this column apply only to the period during which the redesignations were being made.

TABLE 1 (Continued)

KEY VARIABLES

Description	Variable	Run Number		
		H1 - 1.0	H1 - 1.2	H1 - 1.3**
Average Peak-to-Peak Rates (deg/sec)	OMEGAQ	3.8*	3.3*	0.8
	OMEGAR	3.43*	3.0*	2.0
	OMEGAU	3.75*	3.4*	1.3
	OMEGAV	1.5	1.5	1.3

*The above values were taken at peak amplitudes and were not necessarily sustained oscillations.

**Entries in this column apply only to the period dur ng which the redesignations were being made.

TABLE 2
RCS ACTIVITY SUMMARY
(End of Ullage to Touchdown)

Jet No.	Run H1-1.0		Run H1-1.2		Run H1-1.3	
	Jet On Time (sec)	No. of Fires	Jet On Time (sec)	No. of Fires	Jet On Time (sec)	No. of Fires
1	11.119	84	4.101	24	11.032	86
2	9.780	77	9.613	87	10.082	77
3	3.085	9	2.449	8	4.784	15
4	3.067	17	1.125	17	4.563	21
5	12.187	74	8.335	63	11.455	67
6	11.475	73	7.463	56	10.761	58
7	0.904	18	3.033	11	1.073	23
8	0.979	8	1.787	14	0.958	14
9	9.831	82	9.604	87	10.067	77
10	11.101	84	11.165	79	11.034	87
11	3.085	9	2.449	8	4.784	15
12	3.067	17	1.125	17	4.563	21
13	11.515	73	7.454	55	10.795	58
14	12.189	74	8.337	63	11.456	67
15	0.904	18	3.033	11	1.073	23
16	0.979	8	1.787	14	0.958	14
Total On Time of All Jets (sec)	105.267		82.860		109.438	
Total No. of Fires	725		614		723	
Total Propellent (lb)	40.155		31.703		41.683	

3.5 LANDING SEQUENCE WITH ΔRLS REDESIGNATION AFTER PDI, Run H1-1.5

Test Description

Automatic landing including a 10,000-foot downrange redesignation via N69 (ΔRLS method) approximately three minutes after PDI. DOI has been completed and LM is in proper descent orbit at the beginning of the test.

Test Objective

Evaluate the DAP performance during a descent sequence in which a downrange redesignation is performed after PDI.

Initialization Data

The initialization data for this test case are the same as for the nominal descent run, Run H1-1.0.

Timeline

The following is a list of the major events and their times of occurrence.

	Time-Seconds	Event
1)	205.0575	Ullage initiated
2)	212.5605	DPS Engine Ignition Command
3)	213.0565	Ullage completed
4)	418.117	N69 redesignation
5)	725.0745	Enter Visibility Phase Program, P64
6)	869.2909	Enter Automatic Terminal Landing Phase Program, P65
7)	930.5568	LM stop button
8)	931.1398	DPS engine off
9)	931.5568	Touchdown confirmed

The total time between ignition and lunar touchdown was 718.99 seconds or about 12 minutes. The plots presented in Figures 47 through 58 consider only the time interval from ullage to lunar touchdown.

Results

Figures 47 through 58 are plots of the various LGC and environment parameters pertinent to this test case. Table 3 indicates the magnitudes and times of occurrence of certain key variables. Table 4 presents a summary of the RCS activity. Data for Figures 47 through 58 were obtained every fifth DAP cycle or 0.5 second.

The simulated astronaut keyed in a 10,000-foot downrange redesignation via N69 at 418.117 seconds or approximately 3.42 minutes into the burn. The transients introduced into the system by this action were very slight. The pitch rate showed a small spike of 0.35 degree per second at 420 seconds but the other variables were virtually unaffected. The DAP performance for this run was very similar to the nominal descent run and the N69 redesignation perturbed the system very little.

The entrance to P64, the pitchover maneuver, and entrance to P65 for this run occurred approximately eight seconds later than the nominal run. The landing site vector (moon-centered coordinates) for this run was:

$$\overline{RLS} = \begin{bmatrix} 1590435.561 \\ 6952291.469 \\ 20864.623 \end{bmatrix} \text{ meters}$$

while the corresponding vector for the nominal run was:

$$\overline{RLS} = \begin{bmatrix} 1589219.586 \\ 698103.086 \\ 20913.906 \end{bmatrix} \text{ meters}$$

The vector difference between the two landing sites turns out to be 10,050 feet in a downrange direction. This compares favorably with the specified distance of 10,000 feet. The DAP operation and its interface with guidance were found to be nominal for this test case.

FIGURE 47

INNER GIMBAL ANGLE, CDUY

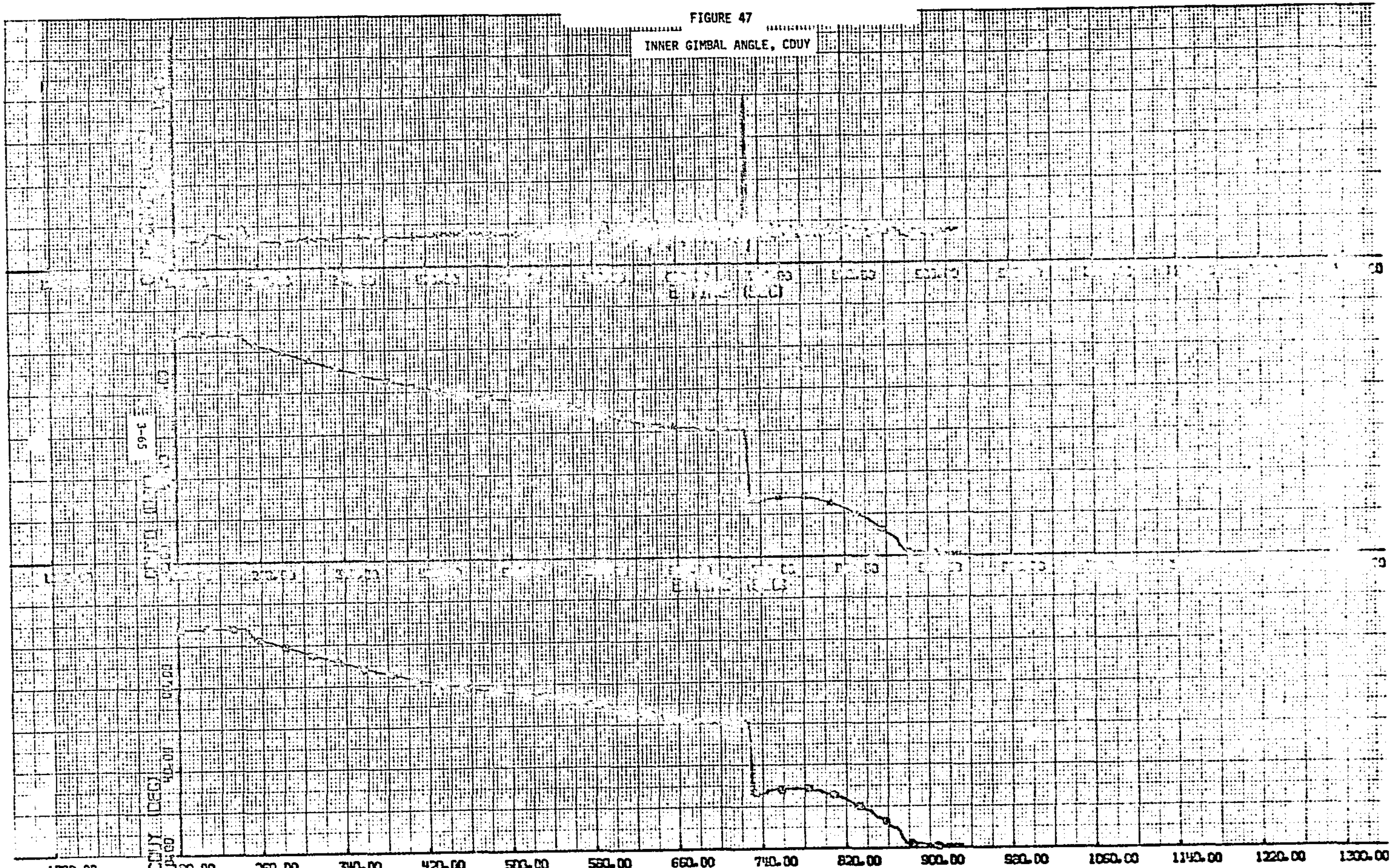


FIGURE 48

PITCH, YAW, AND ROLL ATTITUDE ERRORS

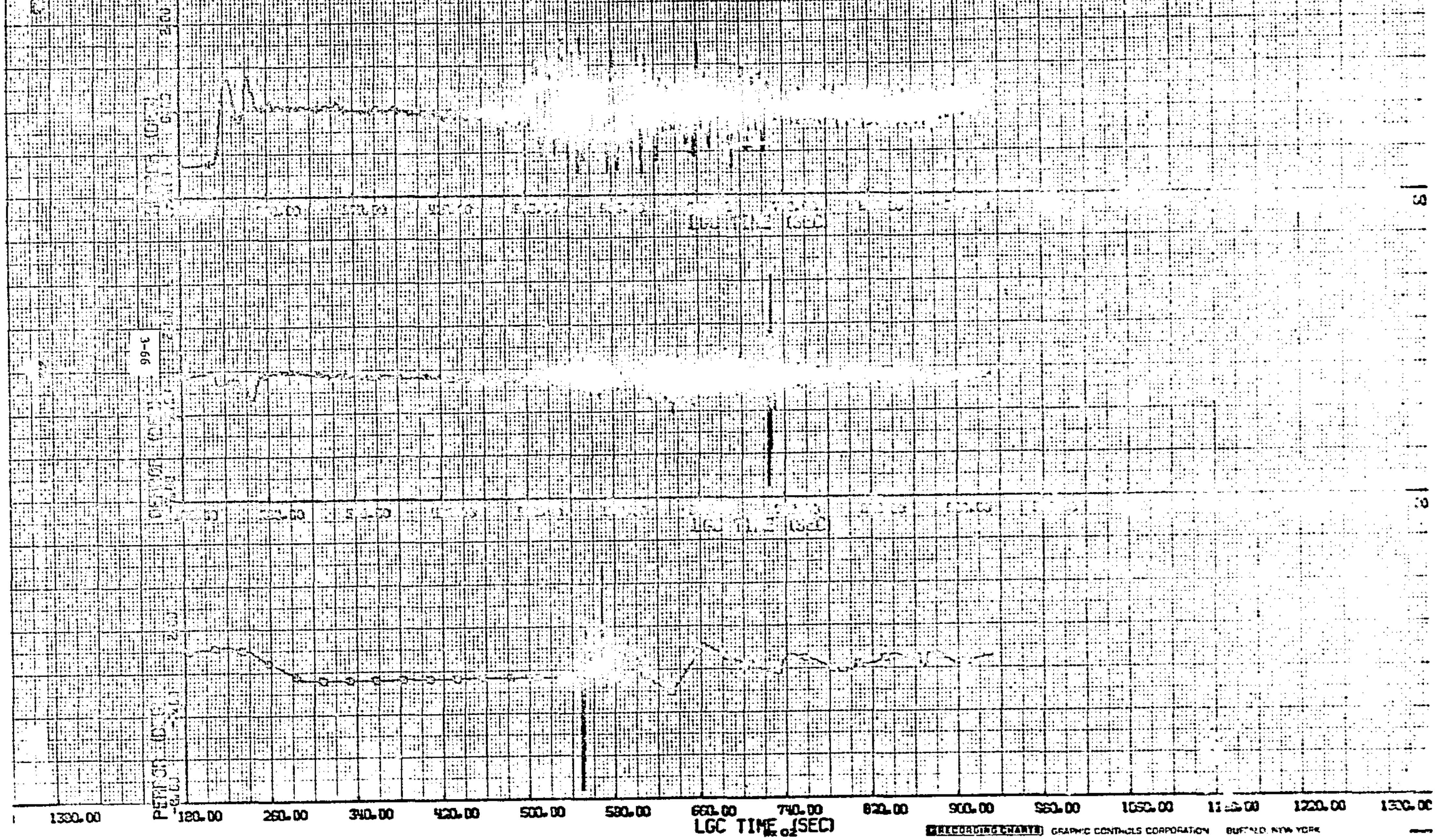


FIGURE 49

U', V' CONTROL AXES ATTITUDE ERRORS

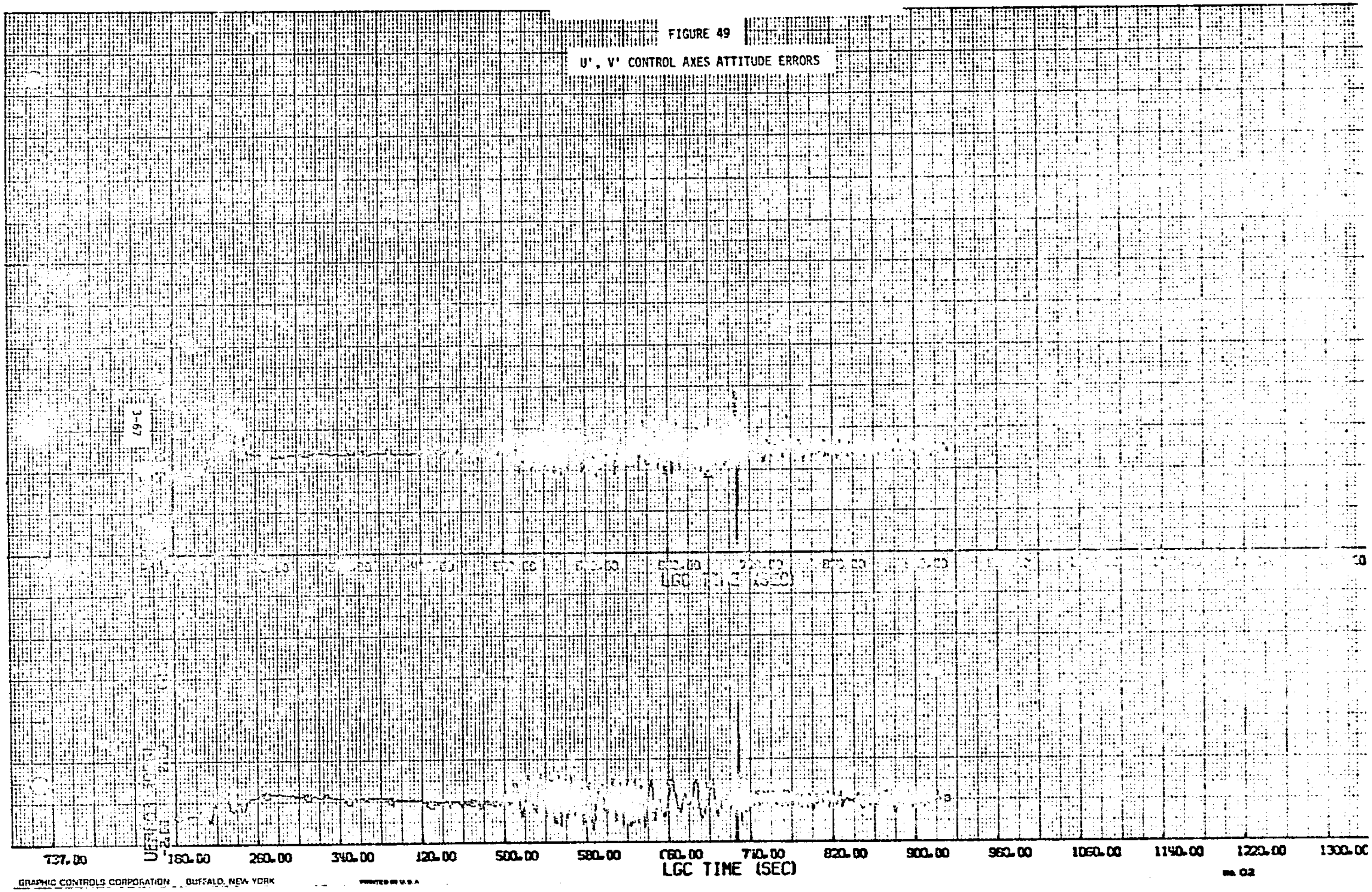


FIGURE 50

YAW BODY RATES: ACTUAL AND ESTIMATED

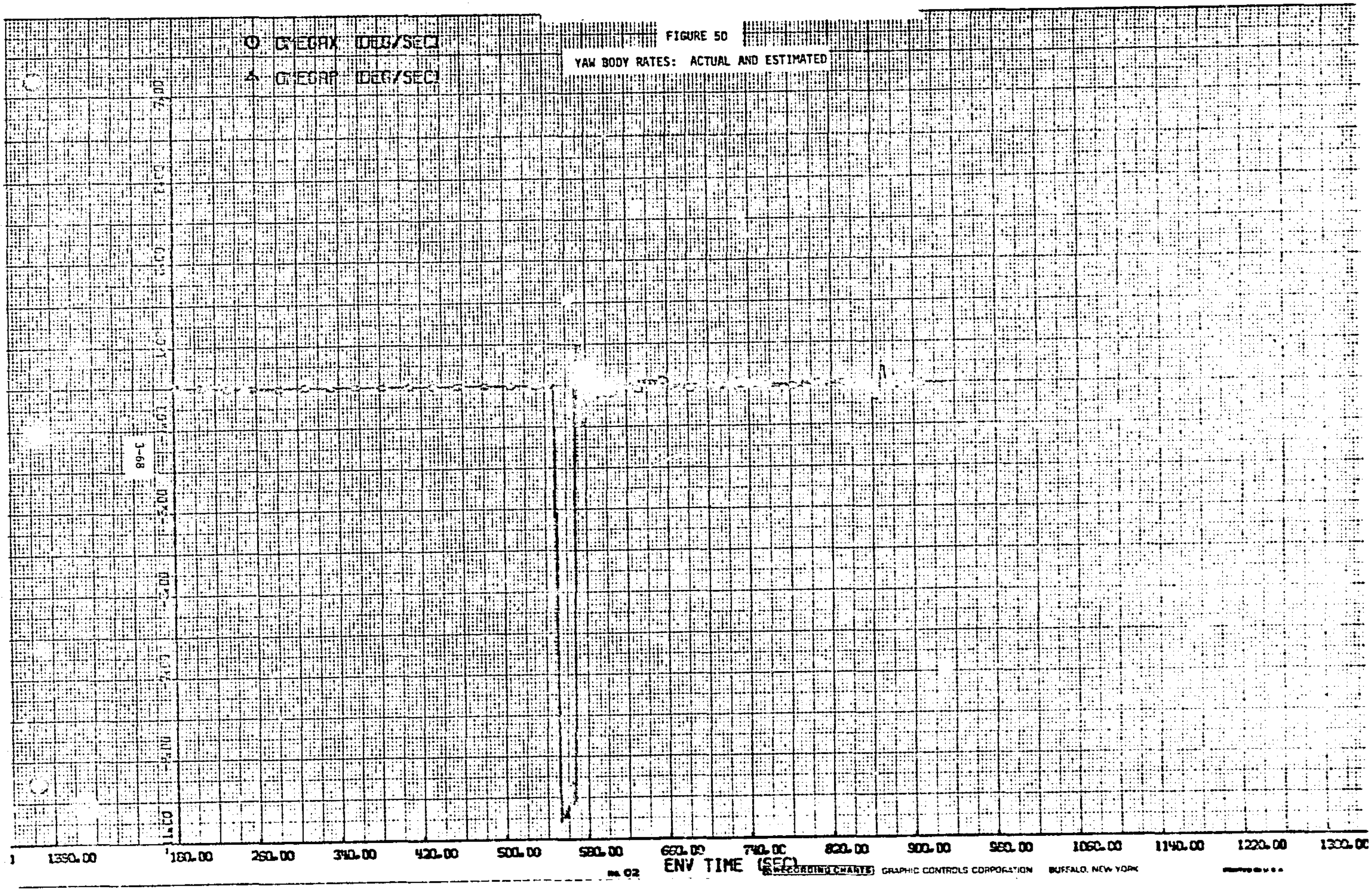


FIGURE 51

PITCH BODY RATES: ACTUAL AND ESTIMATED

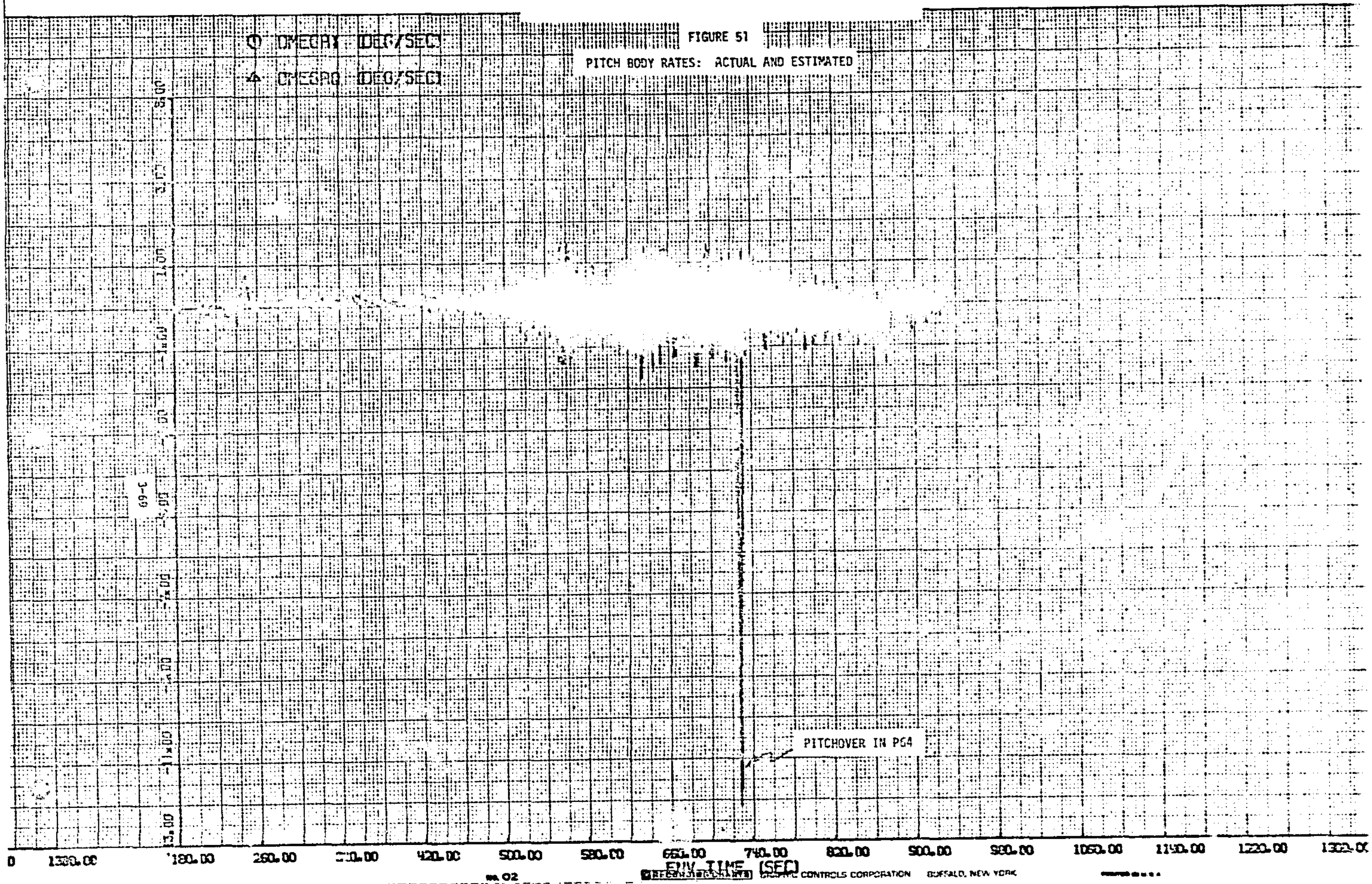
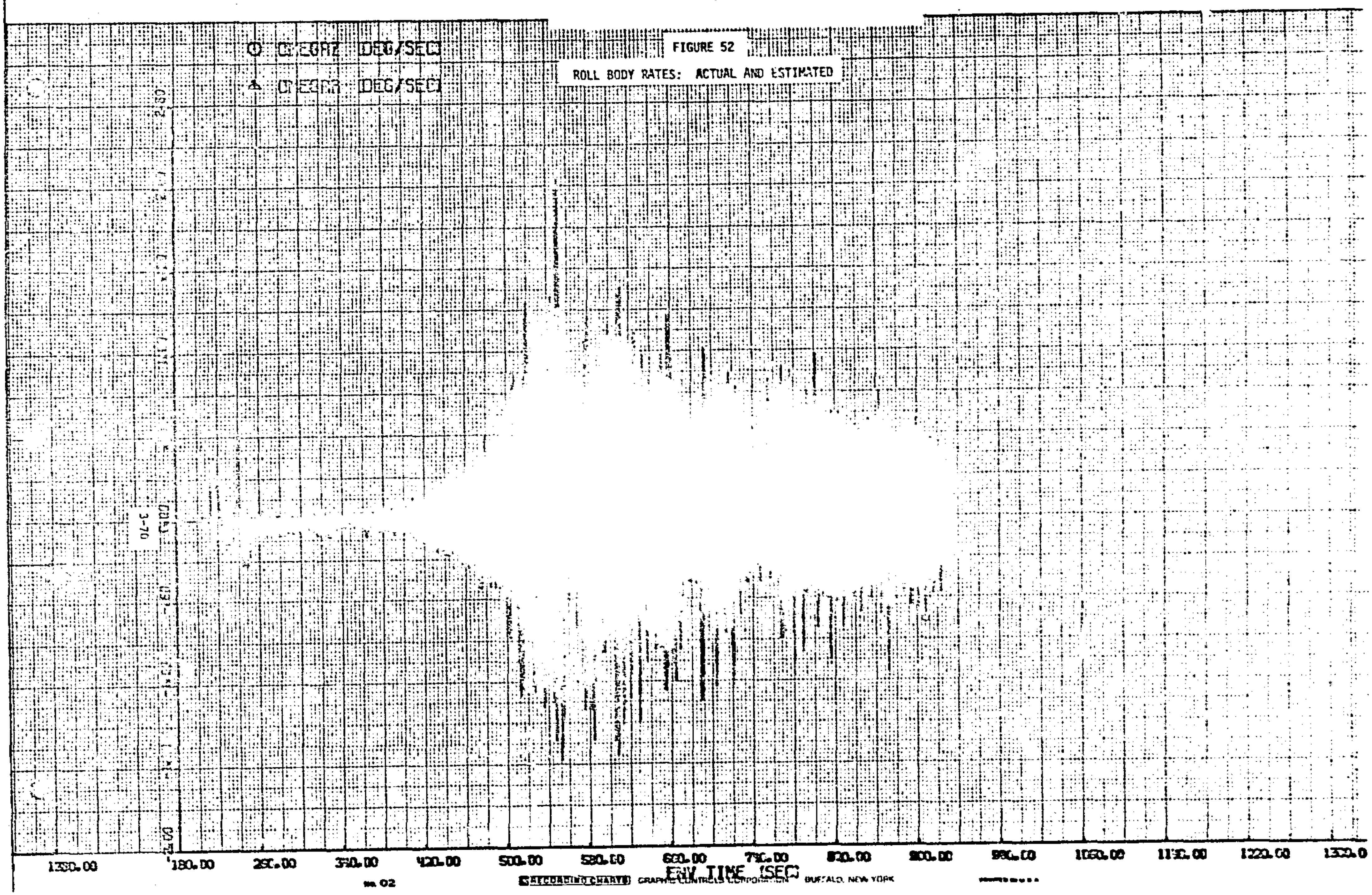


FIGURE 52

ROLL BODY RATES: ACTUAL AND ESTIMATED



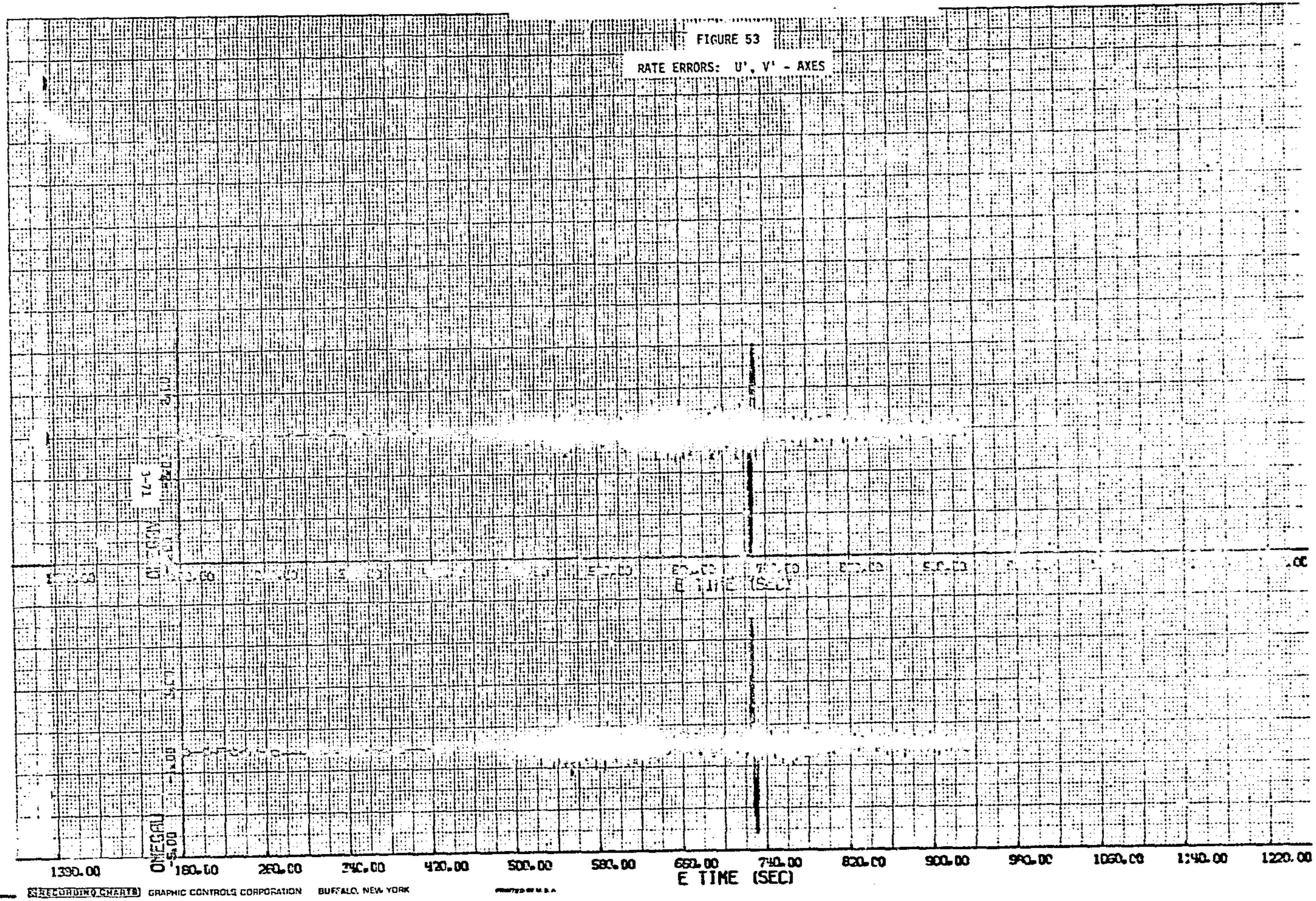


FIGURE 53

RATE ERRORS: U', V' - AXES

FIGURE 54

ESTIMATED BODY OFFSET ACCELERATIONS

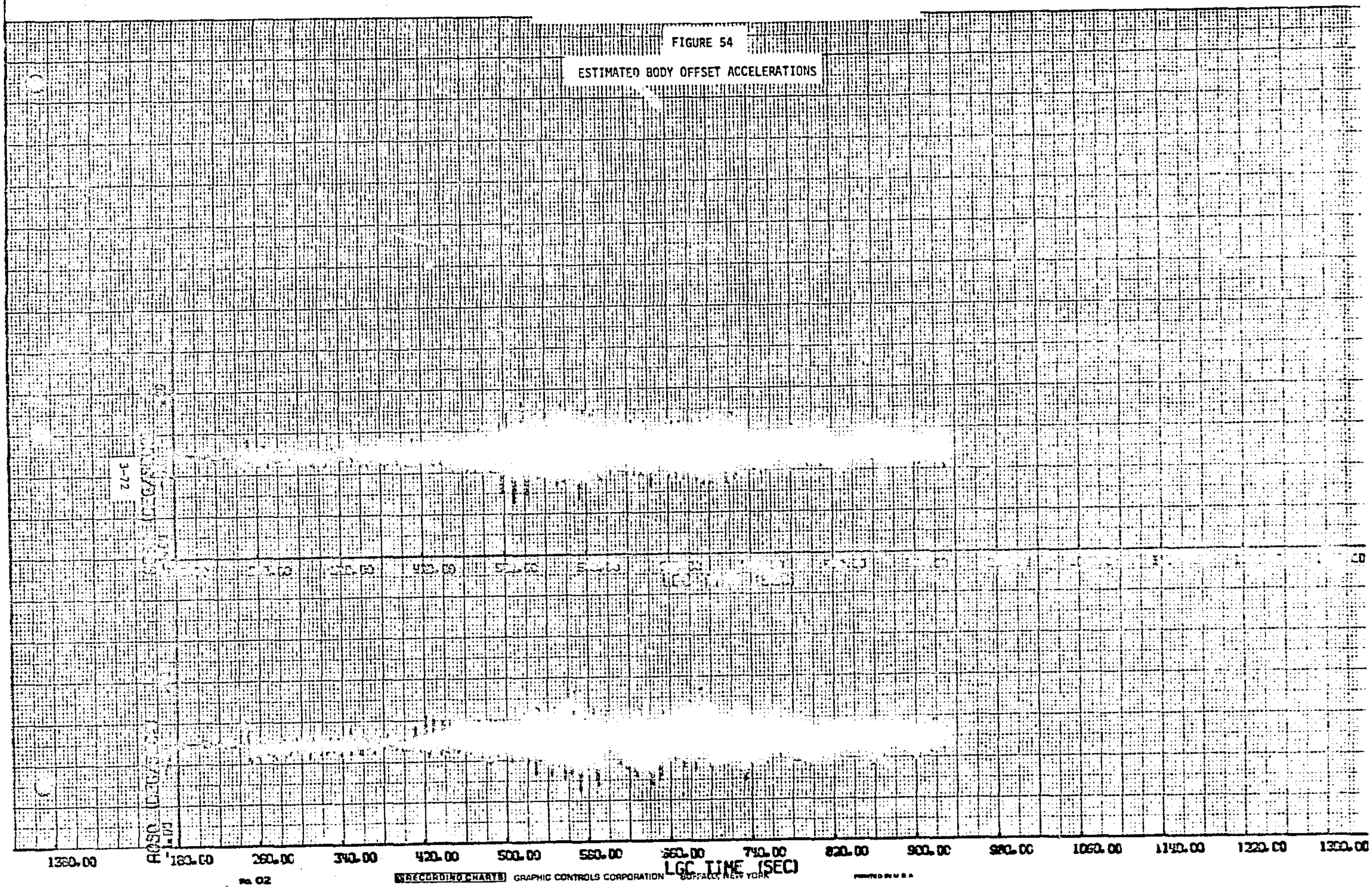
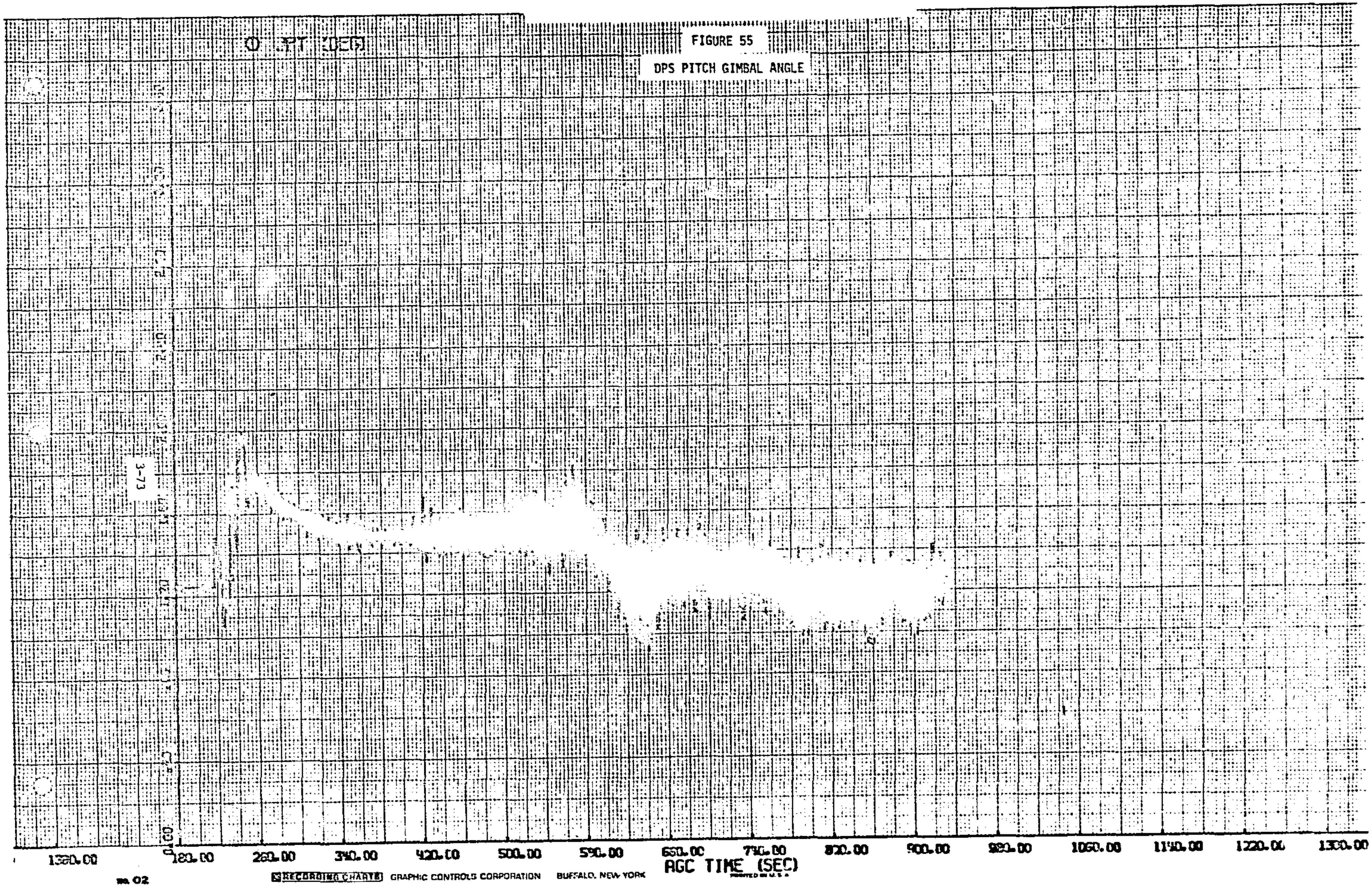


FIGURE 55

DPS PITCH GIMBAL ANGLE



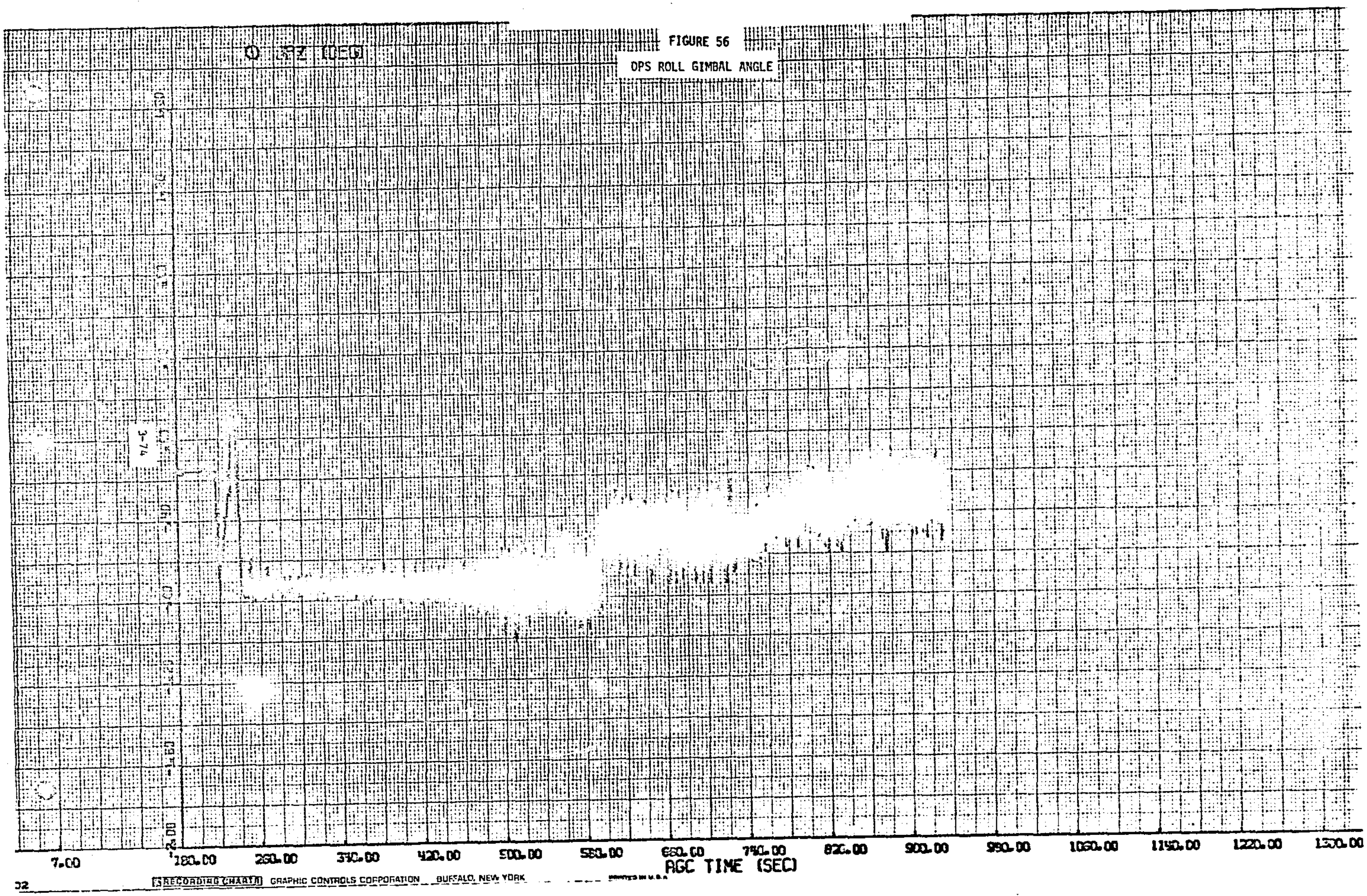
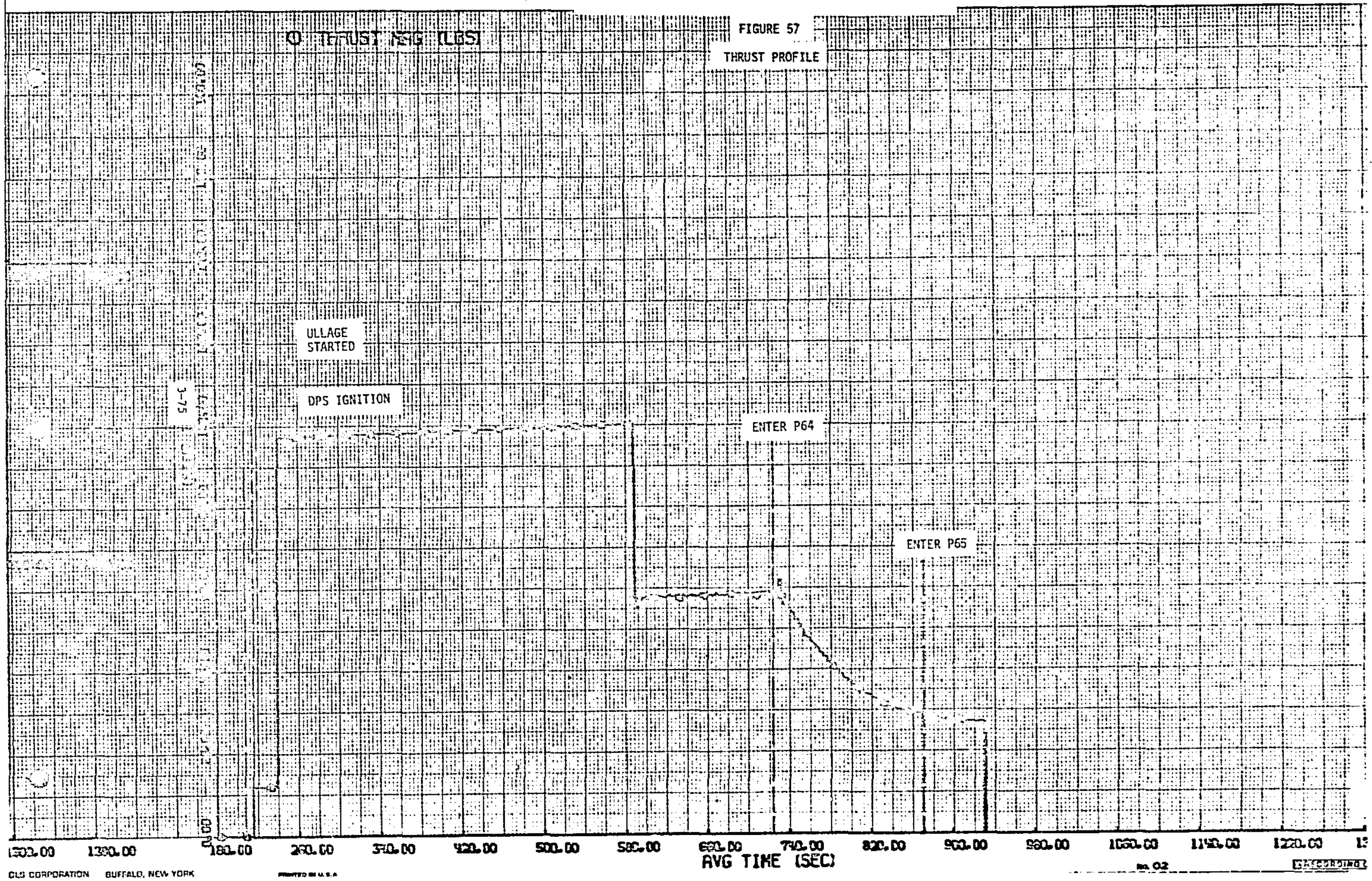


FIGURE 56
DPS ROLL GIMBAL ANGLE
7.00
180.00
260.00
340.00
420.00
500.00
580.00
660.00
740.00
820.00
900.00
980.00
1060.00
1140.00
1220.00
1300.00
AGC TIME (SEC)
RECORDING CHARTS GRAPHIC CONTROLS CORPORATION BUFFALO, NEW YORK

FIGURE 57

THRUST PROFILE



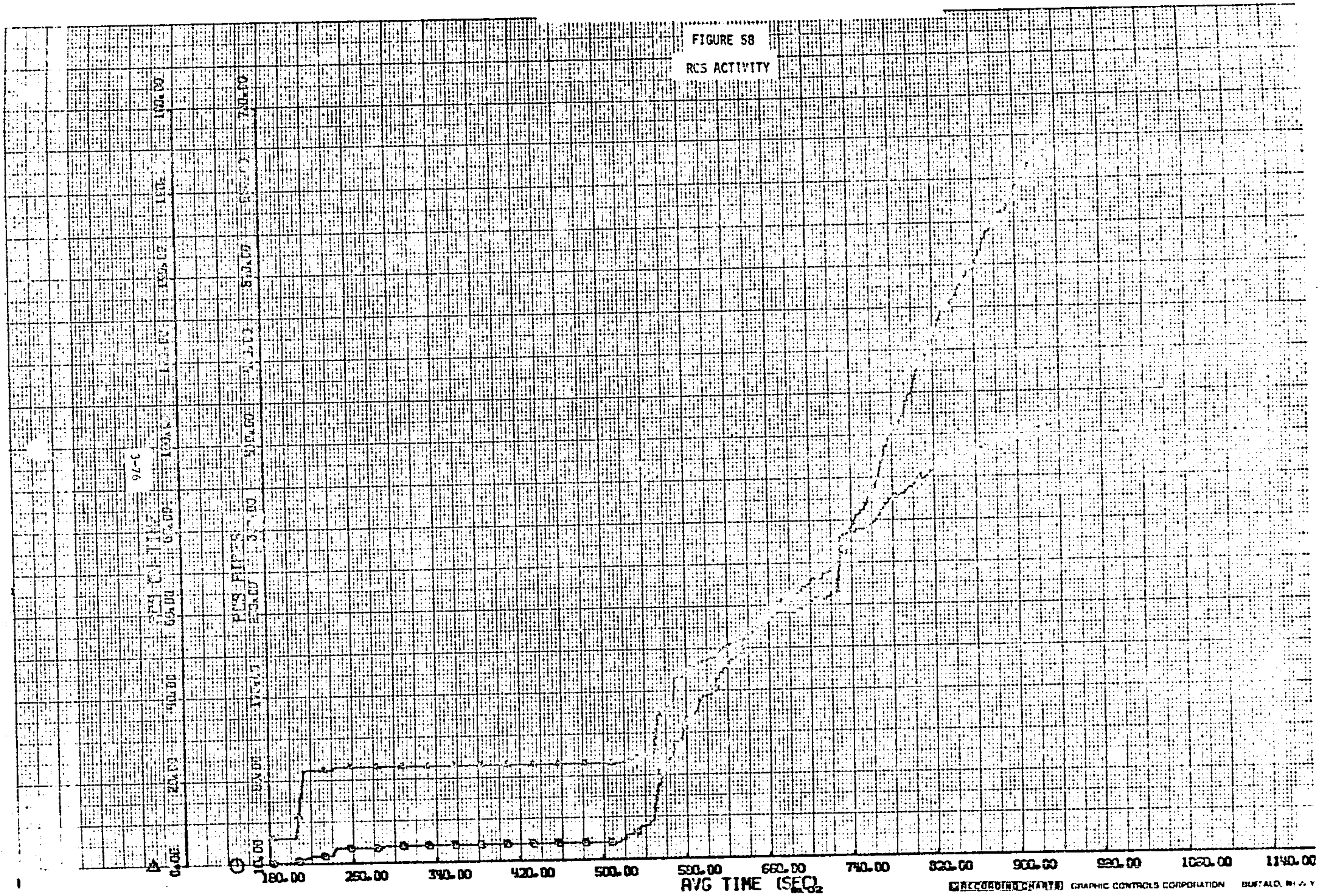


FIGURE 58

RCS ACTIVITY

3.5 DPS/APS ABORT FROM POWERED DESCENT WHILE IN P64; RUN H1-30

Test Description

This test case simulates a DPS/APS abort from a nominal descent sequence at a time late in the Visibility Phase (P64). Because insufficient ΔV via the DPS remains at the time of the abort, this case also includes LM staging and completion of the abort burn with the APS. The abort programs P70 and P71 were entered via astronaut utilization of the ABORT and ABORT STAGE buttons respectively.

Test Objectives

The primary objectives of this test case are to evaluate LUMINARY 1B DAP performance in P70 and to verify that the RCS deadband is sequenced from 0.3 degree in P64 to 1.0 degree in P70. Secondary objectives of this test case are to evaluate the DAP performance during inflight LM staging and subsequent use of abort program P71.

Initialization Data

This simulation was made as a checkpoint restart from the nominal descent Run H1-1.0 which is reported in Section 3.1. This simulation begins at TIME = 720.00 seconds which is 507.44 seconds after ignition of the DPS. Since the same data initialization used for Run H1-1.0 is pertinent to this run refer to Section 3.1 for exact values. The body rates and attitude errors at TIME = 720.00 seconds were

PERROR		+1.0 *	
QERROR	=	+3.0	degrees
RERROR		+1.0	

and

OMEGAX		- 0.2	
OMEGAY	=	-12.0	deg/sec
OMEGAZ		- 1.0	

* These values reflect the last part of the automatic pitchover in P64 which occurs near TIME = 720.00 seconds.

Timeline

The following is a list of the major events of interest and their times of occurrence.

	Time-Seconds	Event
1)	720.0000	Begin simulation in P64
2)	772.5553	LM ABORT button pushed; enter P70
3)	849.9351	Flashing VERB 97 appears on DSKY indicating DPS propellant is near exhaustion
4)	851.4431	LM ABORT STAGE button
5)	851.6820	DPS commanded off
6)	851.7010	LM staged (pyrotechnics fired)
7)	851.8480	APS commanded on
8)	1195.6185	APS commanded off

The total time interval from the decision to abort and the completion of the P71 burn was 423.0632 seconds. The DPS burn length in P70 was 77.3798 seconds. The APS burn length for the remainder of the abort was 343.9175 seconds.

Results

Table 3 contains a list of key variables, their magnitudes and times of occurrence. Table 4 presents a summary of the total RCS activity for the simulation on an individual jet basis. Plots of the various variables of interest are presented in Figures 59 thru 71. These plots were made from data sampled every fifth DAP cycle. This corresponds to 0.5 seconds between points.

This simulation begins in a nominal descent sequence. The Approach Phase (P63) has been completed and the LGC is in program P64. Approximately 55.5 seconds after P64 has been entered, an abort sequence is initiated via the ASTRO portion of the bit-by-bit (B-B-B) Simulator. The ABORT button is pushed and the abort program P70 is subsequently entered. To reduce RCS propellant usage, the deadband is changed from 0.3 degree in P64 to 1.0 degree in either P70 or P71. As shown in Figure 62, the RCS deadband was changed to 1.0 degree at the inception of P70. During the program P64 and prior to P70, the peak-to-peak amplitude of the control axes attitude errors was 0.8 degree. This indicates a 0.3 degree deadband with some overshooting. In P70 a 1.0 degree deadband is maintained.

Upon entering the abort program P70, large guidance commands are issued to adjust the spacecraft attitude to a burn attitude necessary to achieve safe orbit. The requested change in attitude is essentially a large pitch-over. Figures 59 and 60 show the desired gimbal angles (CDUD's) issued to the DAP during this period from the FINDCDUW ROUTINE and the guidance equations. A total pitchover maneuver of 110 degrees was performed. As shown in Figure 61, the DAP responded in a fashion consistent with the nature and magnitudes of the guidance commands issued. Figures 64 and 65 indicate that the spacecraft oscillations resulting from the GTS-RCS fuel slosh interaction (see Reference 3) are somewhat reduced in amplitude at the inception of P70. The low frequency RCS limit cycle (0.1 Hz) is present throughout P70 and most noticeably after completion of the pitchover. Another transient which accompanies those mentioned above is the effect of DPS throttle-up at the entrance to P70. The thrust level in P64 at the time of abort was 4200 pounds. At the entrance to P70, the throttle was commanded to FTP and a thrust level of 10,000 pounds resulted. This almost instantaneous step in thrust level resulted in large changes in gimbal trim error due to engine mount compliance effects. The thrust dependent compliance model produced transients which resulted in -0.35 degree and +0.65 degree mistrims in JPZ and JPY respectively. JPY is the pitch gimbal angular position and JPZ is the roll gimbal angular position. The GTS responded quickly in trimming out these transients as shown in Figures 68 and 69.

If the decision to abort the powered descent is made at a time greater than approximately IGNITION +300 seconds, the ΔV capability remaining with the DPS is insufficient to complete the abort burn to safe orbit. Consequently, when the DPS runs out of propellant the astronaut must push the ABORT STAGE button and continue the burn via the APS. In this simulation the ASTRO section of the simulator monitors the DSKY and waits for flashing verb 97 which indicates engine fail (in this case fuel exhaustion). When this display appeared the remaining DPS fuel had been exhausted and the ABORT STAGE button was pushed. Figures 64 and 65 show the body rates resulting from the staging and fire-in-the-hole (FITH) forces and moments acting on the spacecraft. The pitch and roll rates attained values of +4.5 deg/sec and +8.1 deg/sec respectively. The dynamics of the simulated staging and FITH were found to be consistent with Reference 4. With the utilization of the ABORT STAGE button the LGC switches immediately to program P71.

Due to the fixed thrust vector/c.g. offset of the APS a constant yaw torque appears at the entrance to P71. This constant torque bias of approximately -0.782 ft-lbs forces the DAP into an unsymmetrical P-AXIS limit cycle.

After the staging transients had subsided, the spacecraft response acquired the characteristic ascent stage limit cycle behavior. The frequency of the rate limit cycle (sec Figures 64 and 65) is 0.375-0.380 Hz and corresponds well with values observed in previous testing. Amplitude modulation of body rates and attitude errors as explained in Reference 2 are also present. The proper 1.0 degree deadband is also maintained during P71.

At APS cutoff, the following residuals were obtained from the noun 85 DSKY display

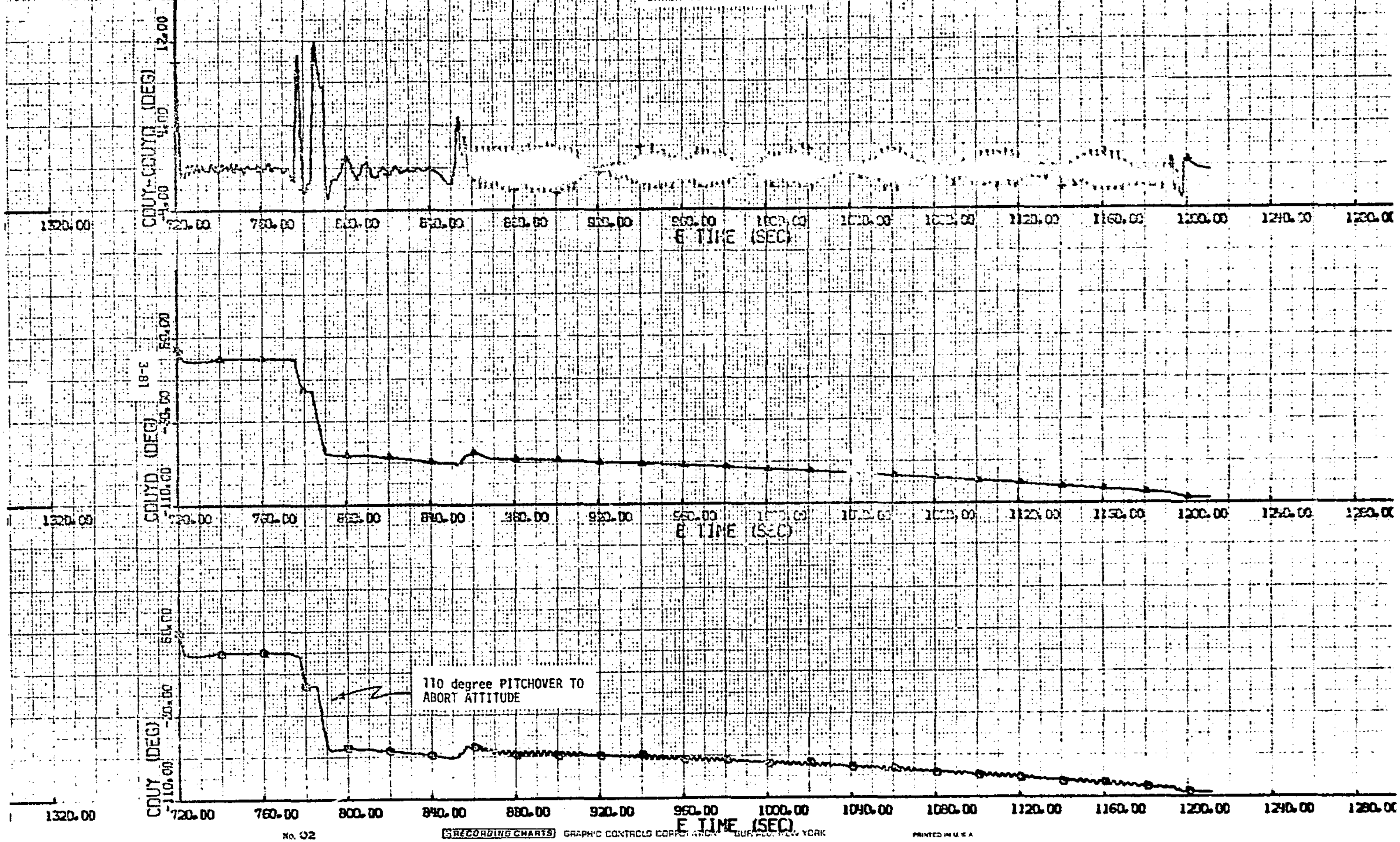
VG(x)	=	-1.0	
VG(y)	=	+0.3	ft/sec
VG(z)	=	+1.0	

In conclusion, the LM DAP performed satisfactorily in a DPS/APS abort late in P64. Successful use of abort programs P70 and P71 was demonstrated. Proper deadband sequencing was verified for the P64 to P70 transition.

DPS ABORT RUN H1-3.D

FIGURE 59

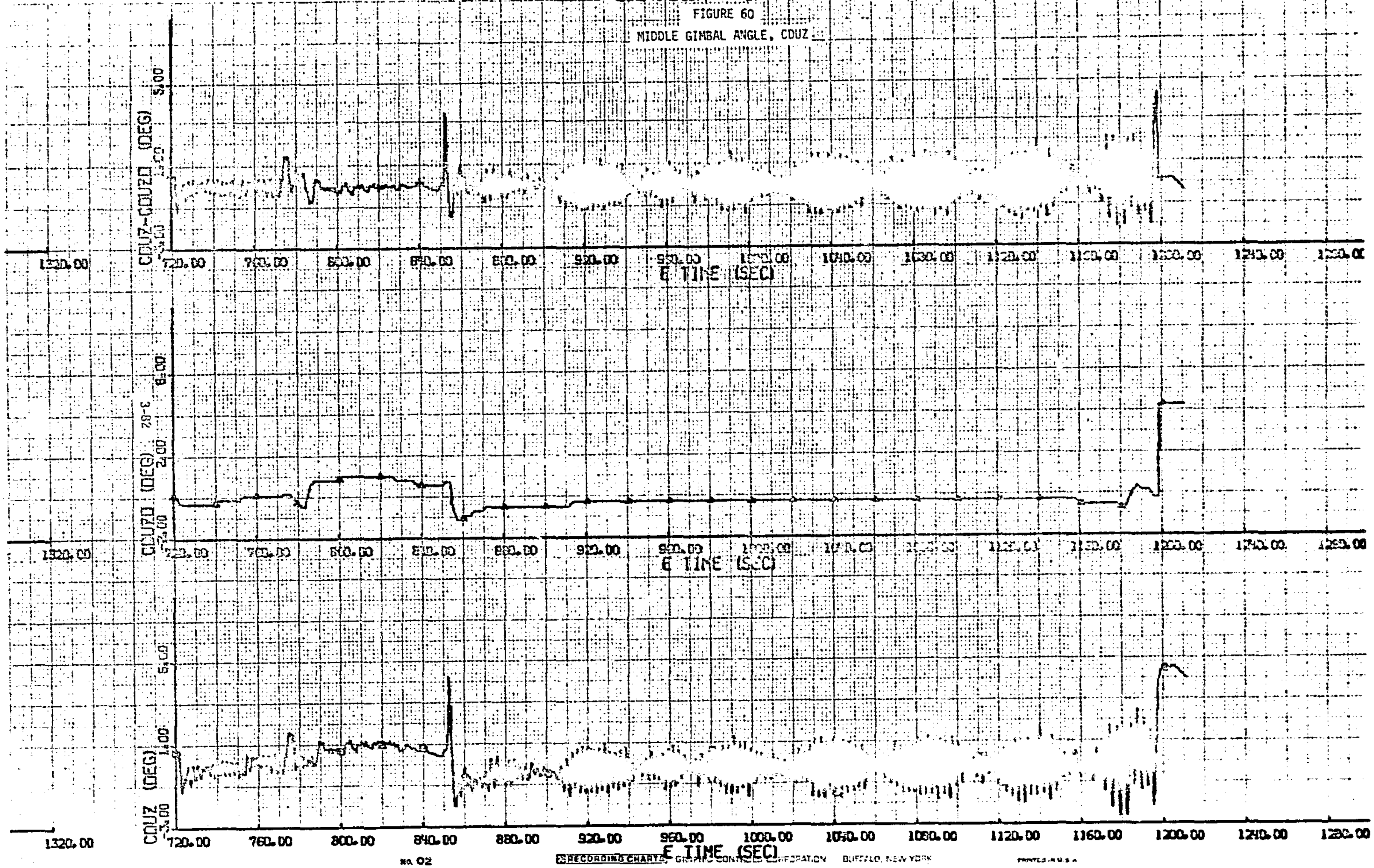
INNER GIMBAL ANGLE, CDUY



DPS ABORT RUN H1-3.0

FIGURE 60

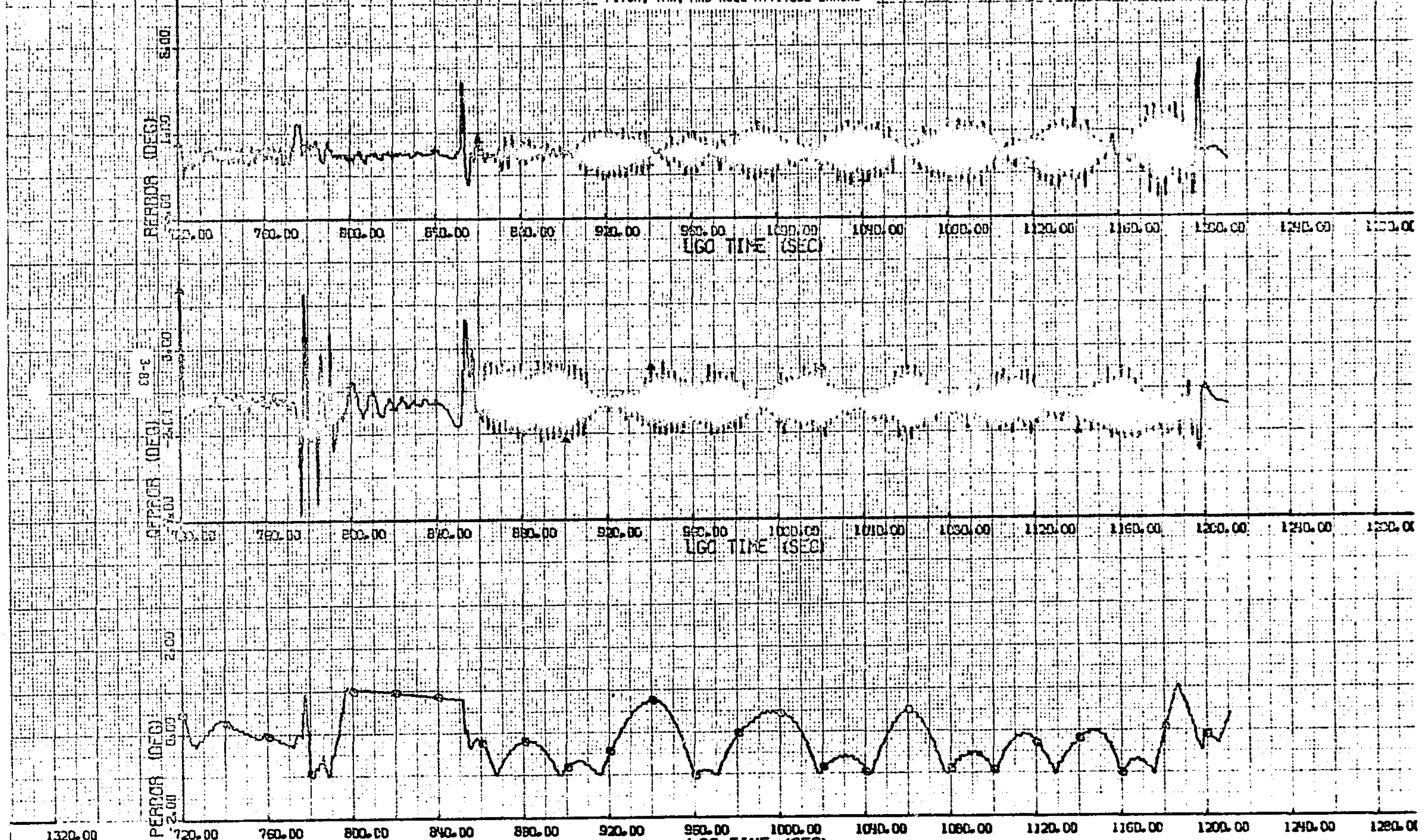
MIDDLE GIMBAL ANGLE, CDUZ



DPS ABORT RUN H1-3.0

FIGURE 61

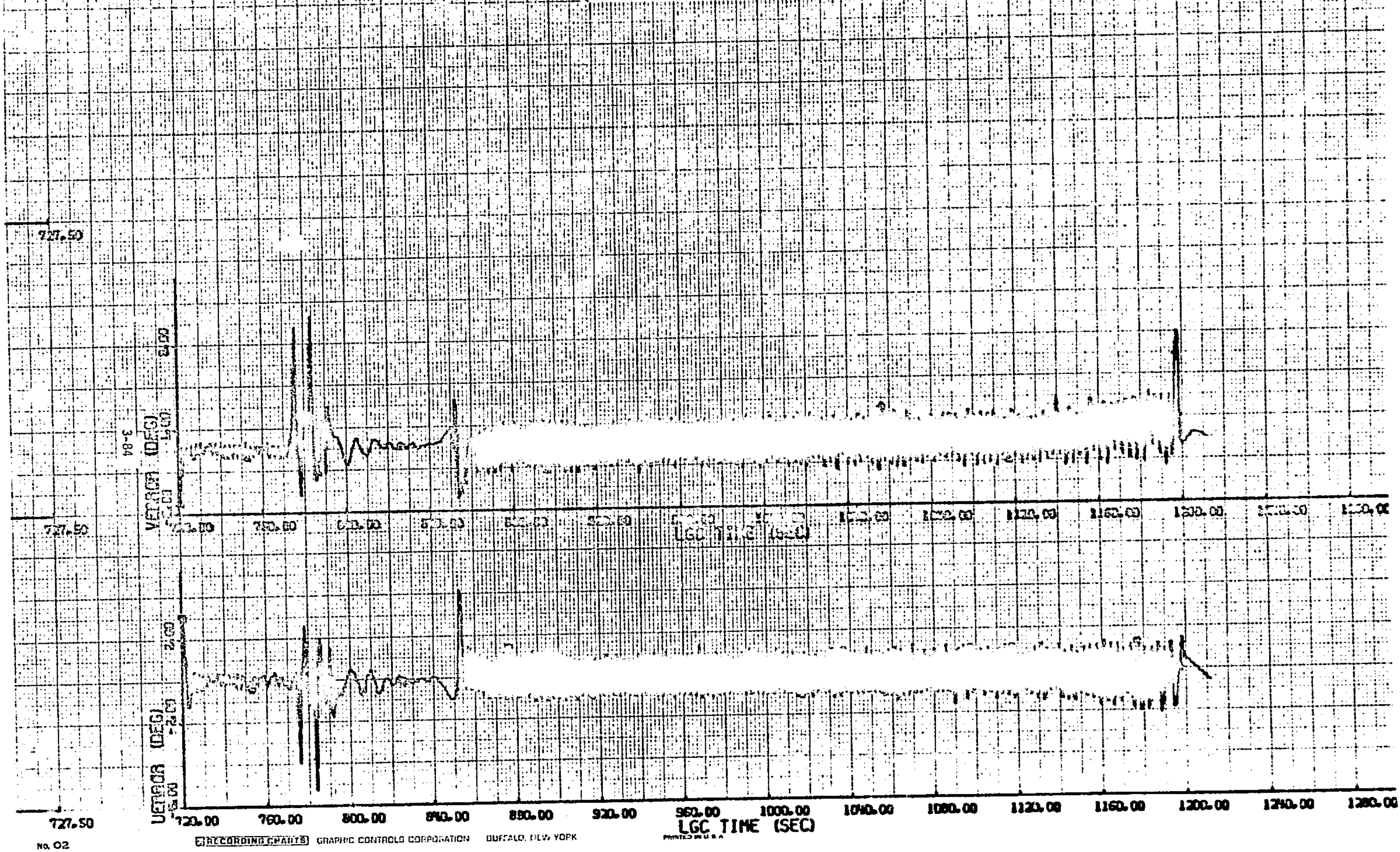
PITCH, YAW, AND ROLL ATTITUDE ERRORS



DPS ABORT RUN H1-3.0

FIGURE 62

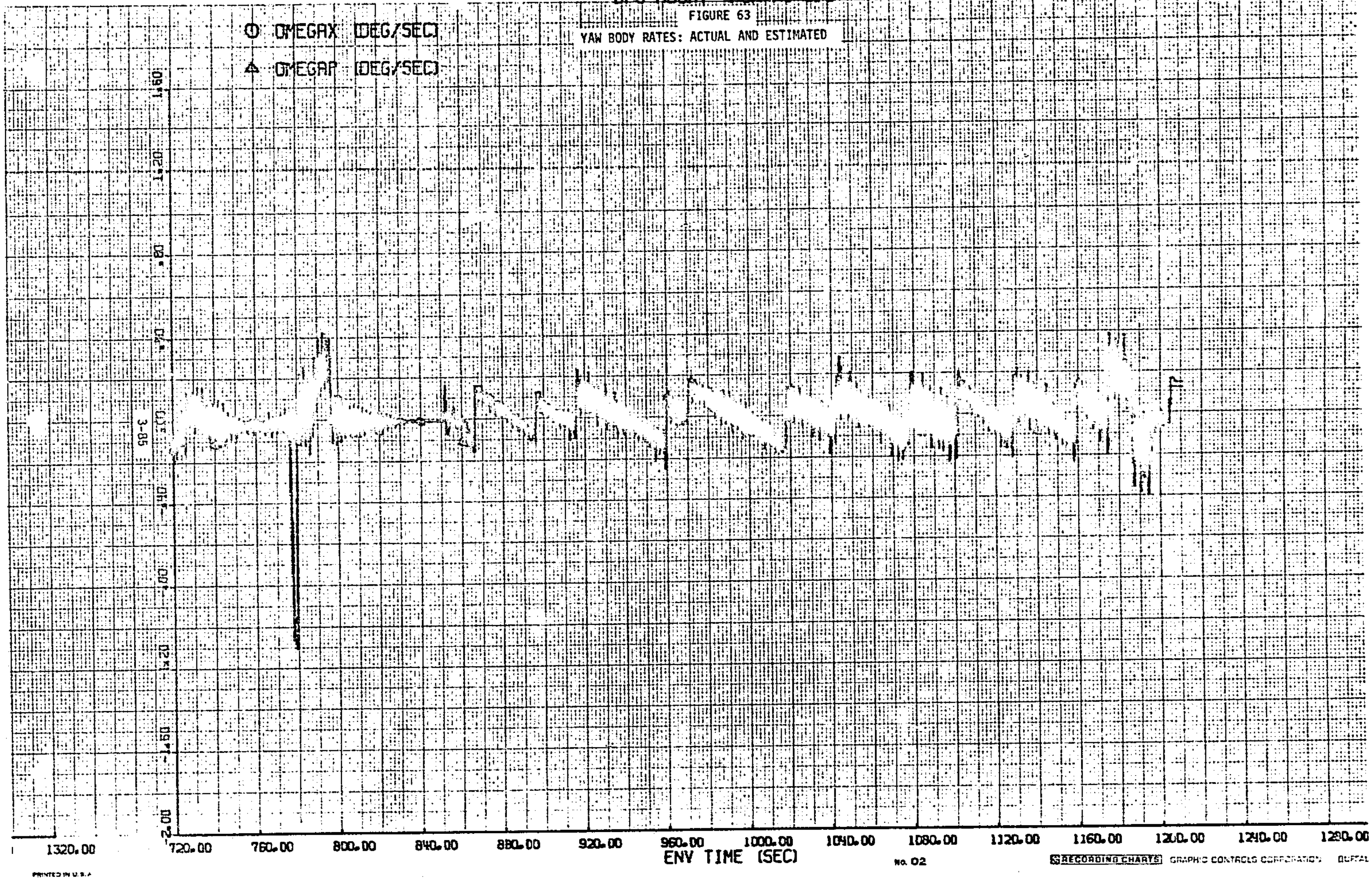
U', V' CONTROL AXES ATTITUDE ERRORS



DPS ABORT RUN H1-3.0

FIGURE 63

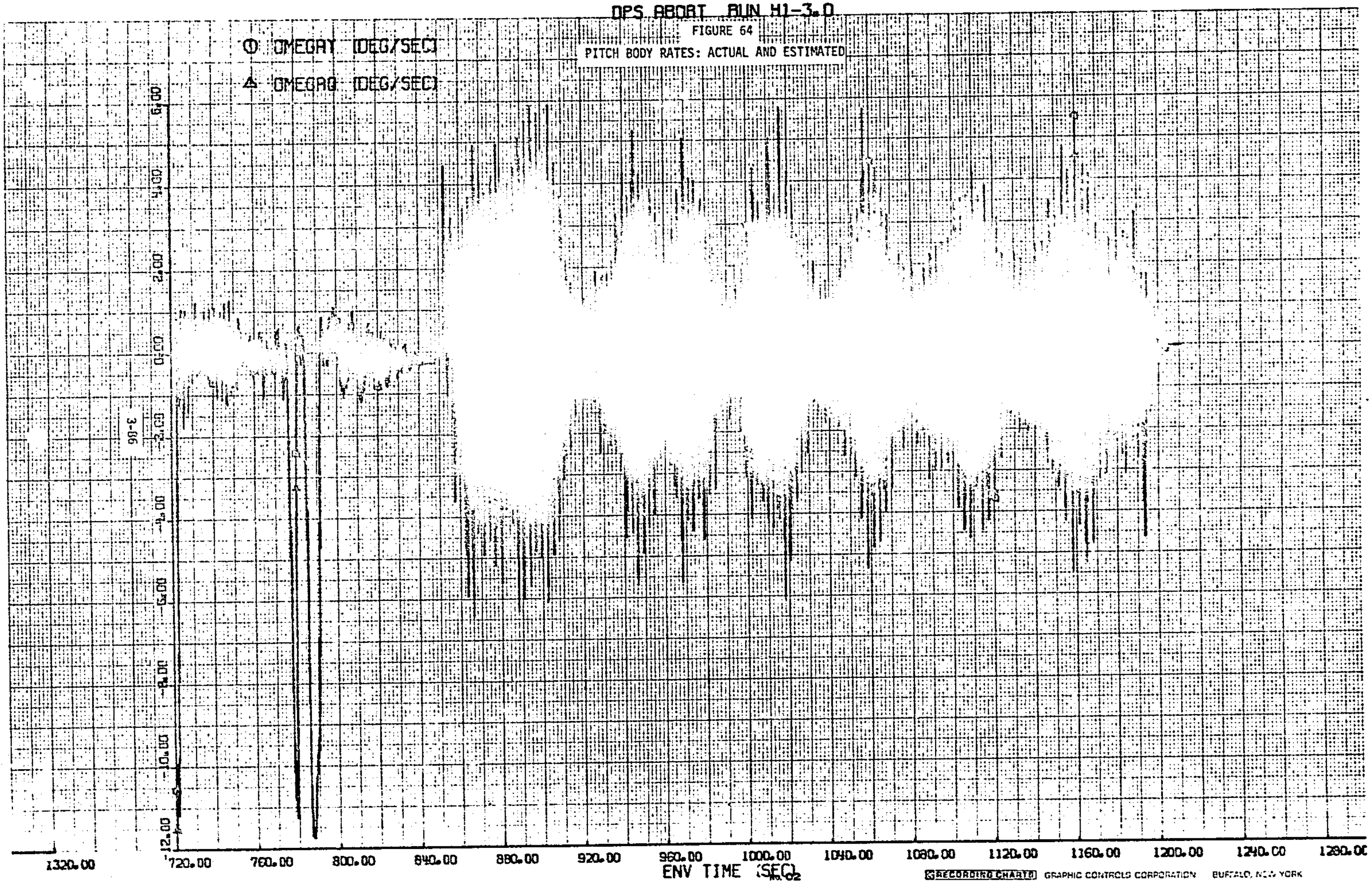
YAW BODY RATES: ACTUAL AND ESTIMATED



DPS ABORT RUN H1-3.0

FIGURE 64

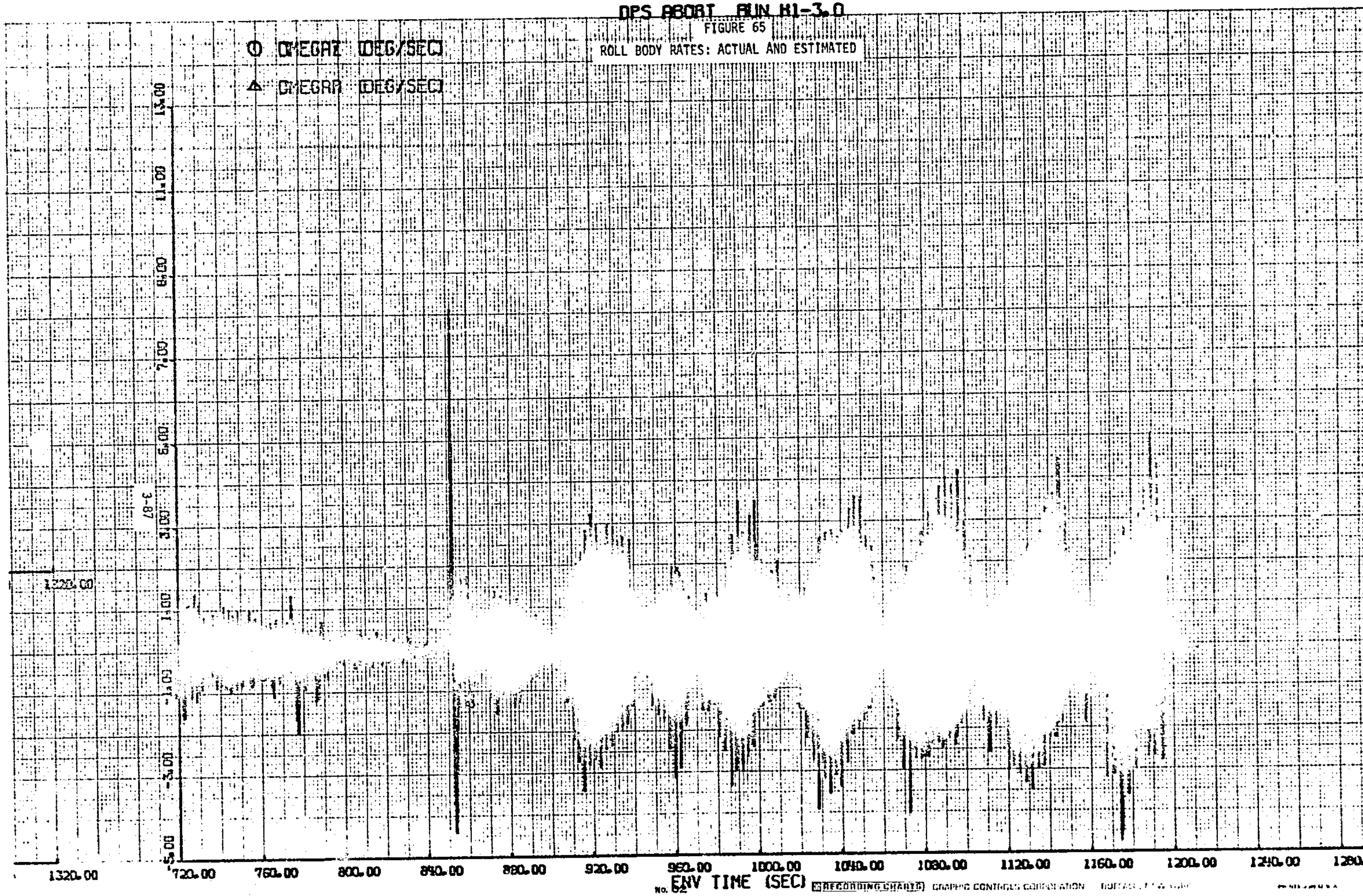
PITCH BODY RATES: ACTUAL AND ESTIMATED



DPS ABORT RUN H1-3.0

FIGURE 65

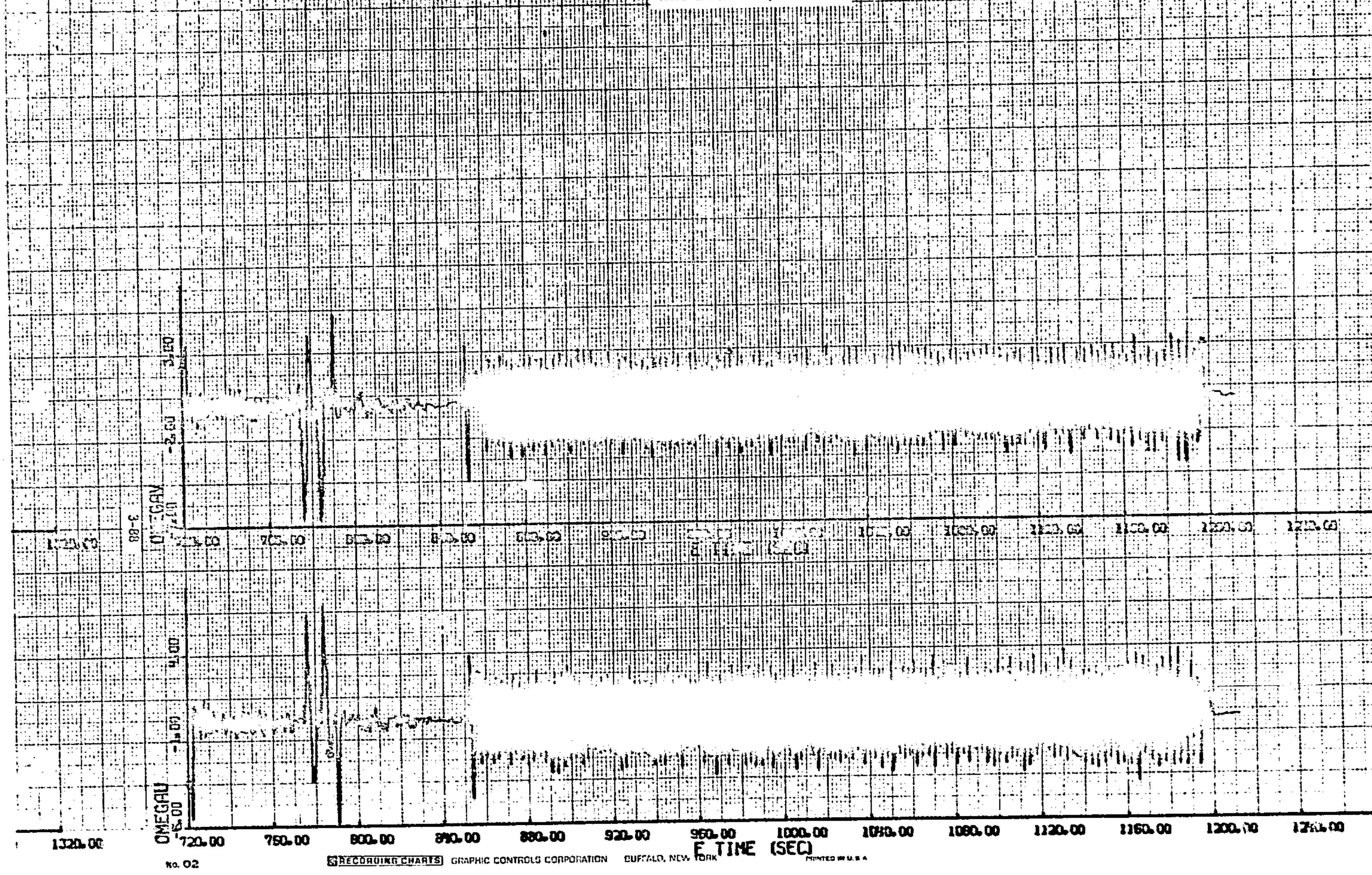
ROLL BODY RATES: ACTUAL AND ESTIMATED



DPS ABORT RUN H1-3.0

FIGURE 66

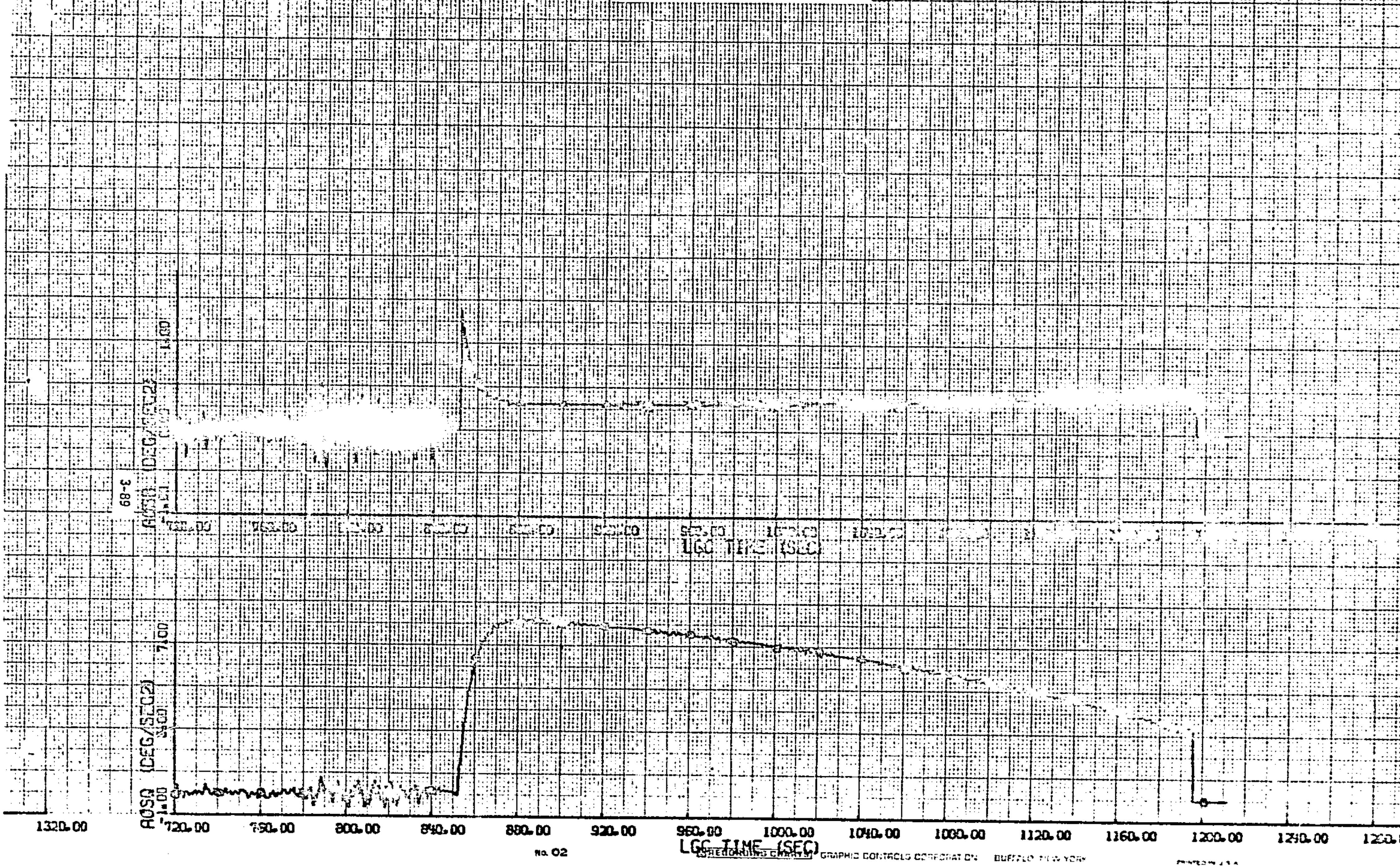
RATE ERRORS: U', V' - AXES



DPS ABORT RUN H1-3.0

FIGURE 67

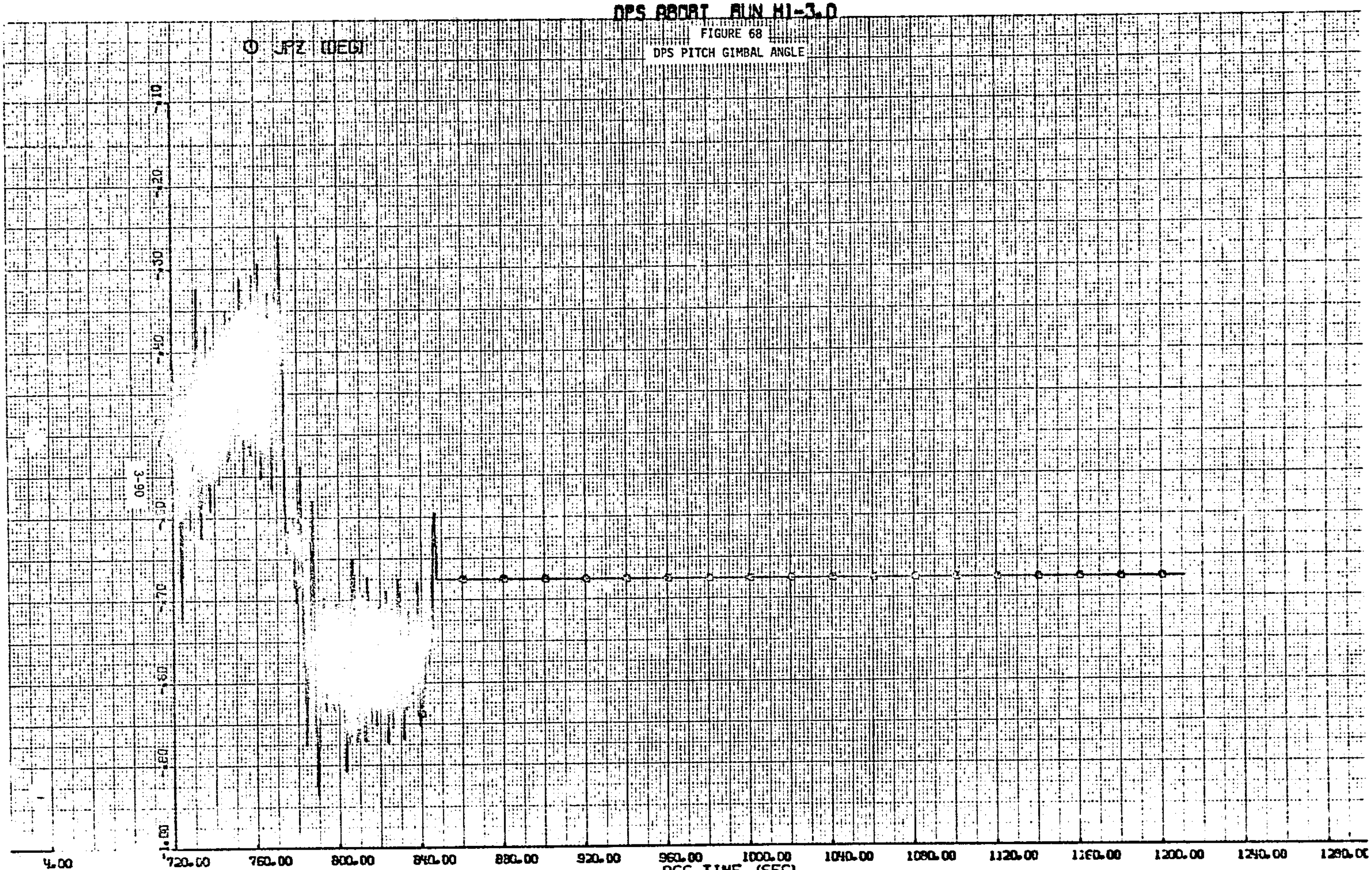
ESTIMATED BODY OFFSET ACCELERATIONS



DPS ABORT RUN H1-3.0

FIGURE 68

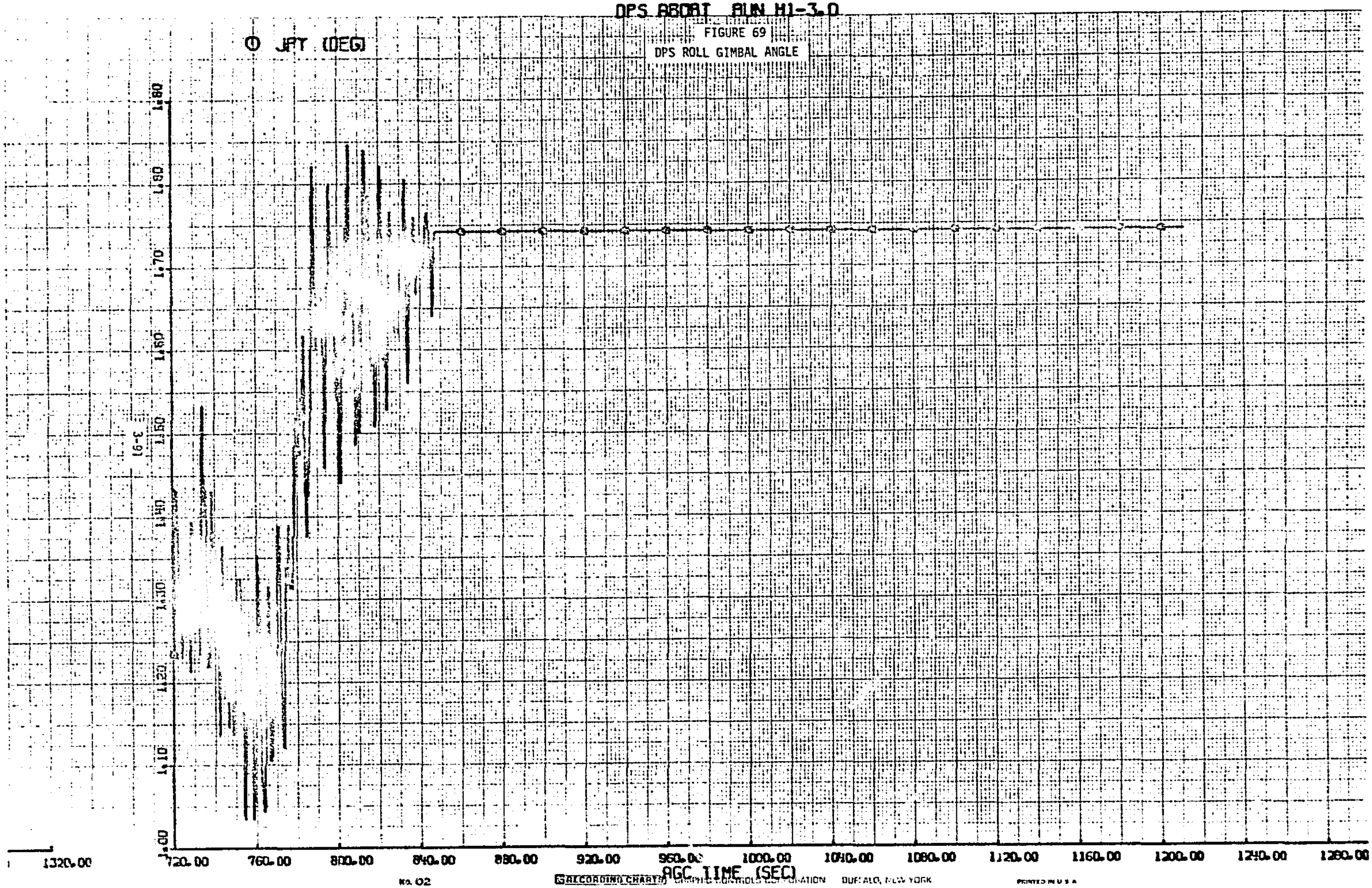
DPS PITCH GIMBAL ANGLE



DPS ABORT RUN H1-3.0

FIGURE 69

DPS ROLL GIMBAL ANGLE



DPS ABORT RUN H1-3.0

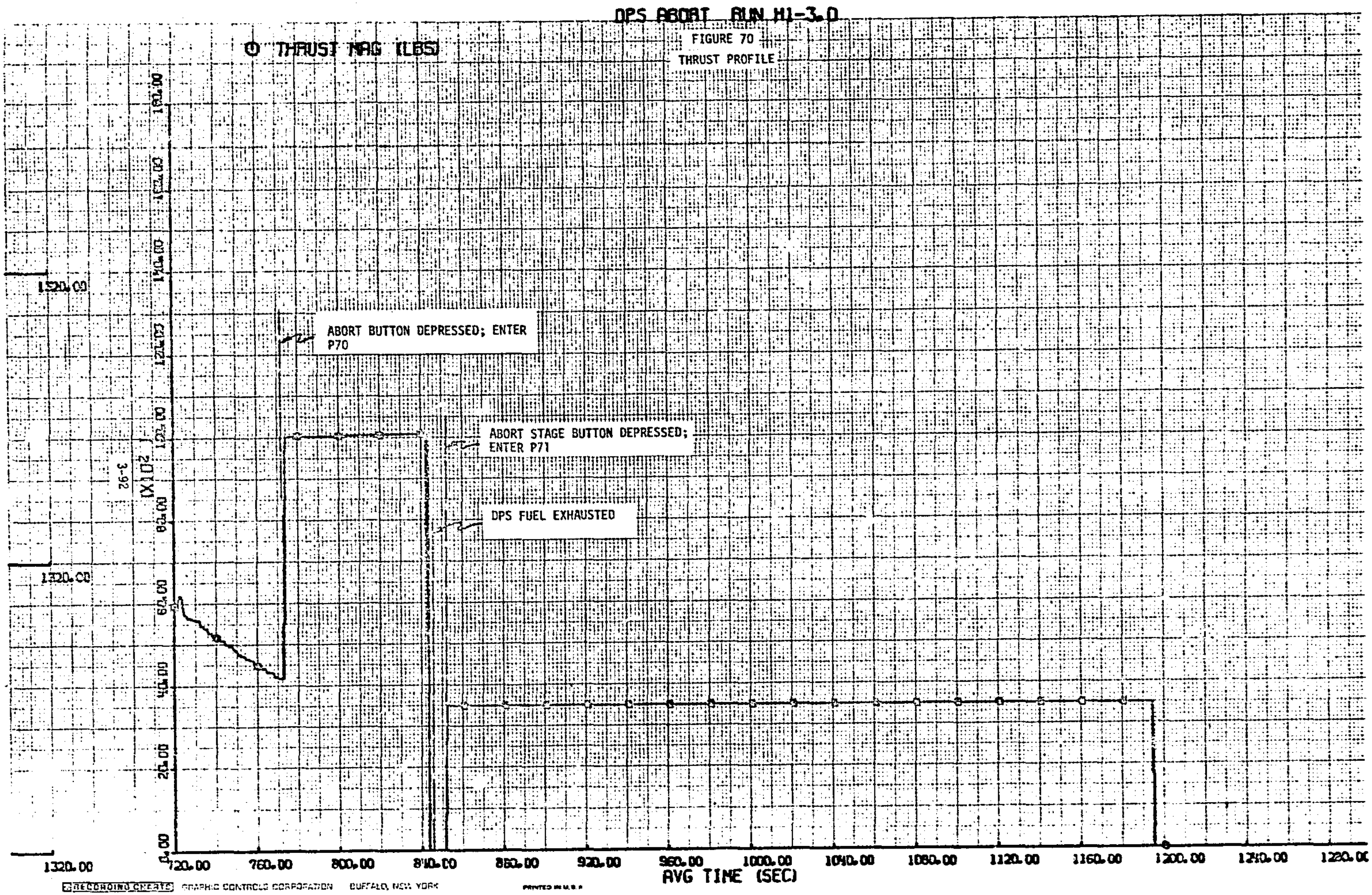


FIGURE 70
THRUST PROFILE

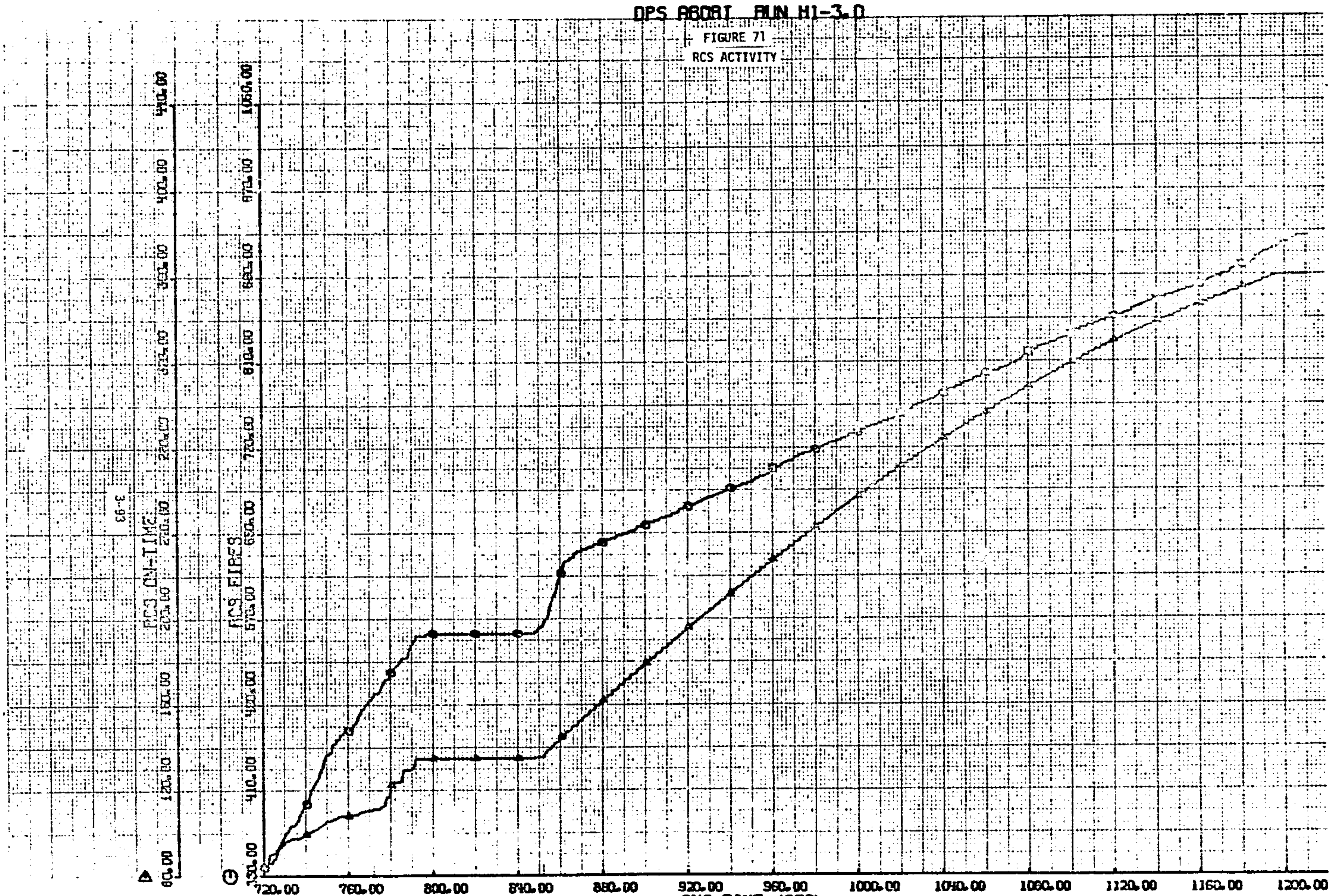


FIGURE 71
RCS ACTIVITY

3.7 APS ABORT FROM POWERED DESCENT WHILE IN P64, RUN H1-3.1

Test Description

This test case simulates an APS abort from a nominal descent sequence at a time late in the visibility phase (P64).

This test is identical to Run H1-3.0 except that the ABORT STAGE button is utilized at the time of the decision to abort.

Test Objectives

The objectives of this test case are to evaluate the LUMINARY 1B DAP performance in P71 and to verify proper sequencing of the RCS deadband from 0.3 degree in P64 to 1.0 degree in P71.

Initialization Data

As with Run H1-3.0 reported in the previous section, this test case was generated through a checkpoint restart from the nominal descent Run H1-1.0. Consequently, all initialization data pertinent to this case is defined in Section 3.1. This case begins with a checkpoint taken at TIME 720.00. This time is late in P64 and the body rates and attitude errors were

PERROR		+0.5	*	
QERROR	=	+5.2		Degrees
RERROR		+0.5		

and

OMEGAX		- 0.2	*	
OMEGAY	=	-11.0		Deg/Sec
OMEGAZ		- 1.0		

* These values represent the end of the automatic pitchover in P64.

Timeline

The following list presents the major events of interest and their times of occurrence.

	Time-Seconds	Event
1)	720.0000	Begin Simulation in P64
2)	772.5553	LM ABORT STAGE button pushed; enter P71
3)	772.9833	DPS commanded off
4)	773.0023	LM staged (pyrotechnics fired)
5)	773.1493	APS commanded on
6)	1196.3385	APS commanded off

The total time between the decision to abort and completion of the P71 burn was 423.7832 seconds. The actual APS burn time was 423.1892 seconds.

Results

Table 3 presents a list of key variables, their magnitudes, and times of occurrence. Table 4 represents a summary of the total RCS activity on an individual jet basis. Plots of important variables are presented in Figures 72 thru 82. These plots were made from data sampled every fifth DAP cycle which corresponds to 0.5 seconds between points.

This run begins under the same conditions as Run H1-3.1 reported in the previous section. The major difference between the two simulations is that for this run, the ASTRO section of the B-B-B Simulator pushes the ABORT STAGE button at the decision to abort instead of the ABORT button. Vehicle staging occurs immediately and the entire abort burn is performed using the APS. As shown on the TIMELINE, the ABORT STAGE button is utilized and the abort program P71 is immediately entered. The DPS is commanded off and then the vehicle is staged followed by the APS on command.

Upon entrance to P71 the RCS deadband is changed from 0.3 degree in P64 to 1.0 degree in P71. This change is essential due to the possible high RCS consumption which would be associated with a 0.3 degree deadband PGNCS controlled APS burn. As shown in Figure 75, the control axes attitude errors are contained within a 1.0 degree deadband during P71 indicating proper updating.

The large moments associated with the vehicle staging and APS FITH produce rather violent transients on the spacecraft motion. As shown in Figures 77 and 78, the maximum pitch and roll rates generated during these transients were +4.0 deg/sec and +8.7 deg/sec in pitch and roll respectively. The DAP performed well in maintaining spacecraft control under the influence of these large transients. Immediately following the FITH transients, the guidance equations request a large pitchover to an attitude necessary to achieve a safe orbit. Figures 72 and 73 show the desired gimbal angles during the abort burn. A total pitchover of 110 degrees is requested and as shown the DAP performs well in responding to these guidance commands. After completion of the large attitude change, the vehicle response aquires the characteristic 0.38 Hz ascent stage limit cycle. Interestingly, amplitude modulation of the attitude errors and body rates does not occur until approximately 120 seconds after completion of the pitchover. As with Run A1-3.0 reported in the previous section, a constant yaw torque appears with the entrance to P71. As discussed earlier, this constant yaw torque is the result of the fixed thrust vector/c.g. offset of the APS. The P71 burn continues in a nominal fashion. A noticeable increase in deadband overshooting is observed toward the end of the burn as the inertias become smaller and the vehicle becomes more "sporty". Just prior to cutoff as the APS fuel nears depletion the vehicle c.g. crosses over the body axes. This results in very small offset accelerations due to thrust misalignment. This phenomena was observed in Reference 2. Changes were supposedly made to the phase plane configurations to generate symmetrical limit cycles for small offsets. As discussed in Reference 5 the changes to be implemented were not sufficient to fully correct the problem. As shown in Figure 75, the control axes attitude errors, particularily VERROR, hang off on the deadband for small values of AOS.

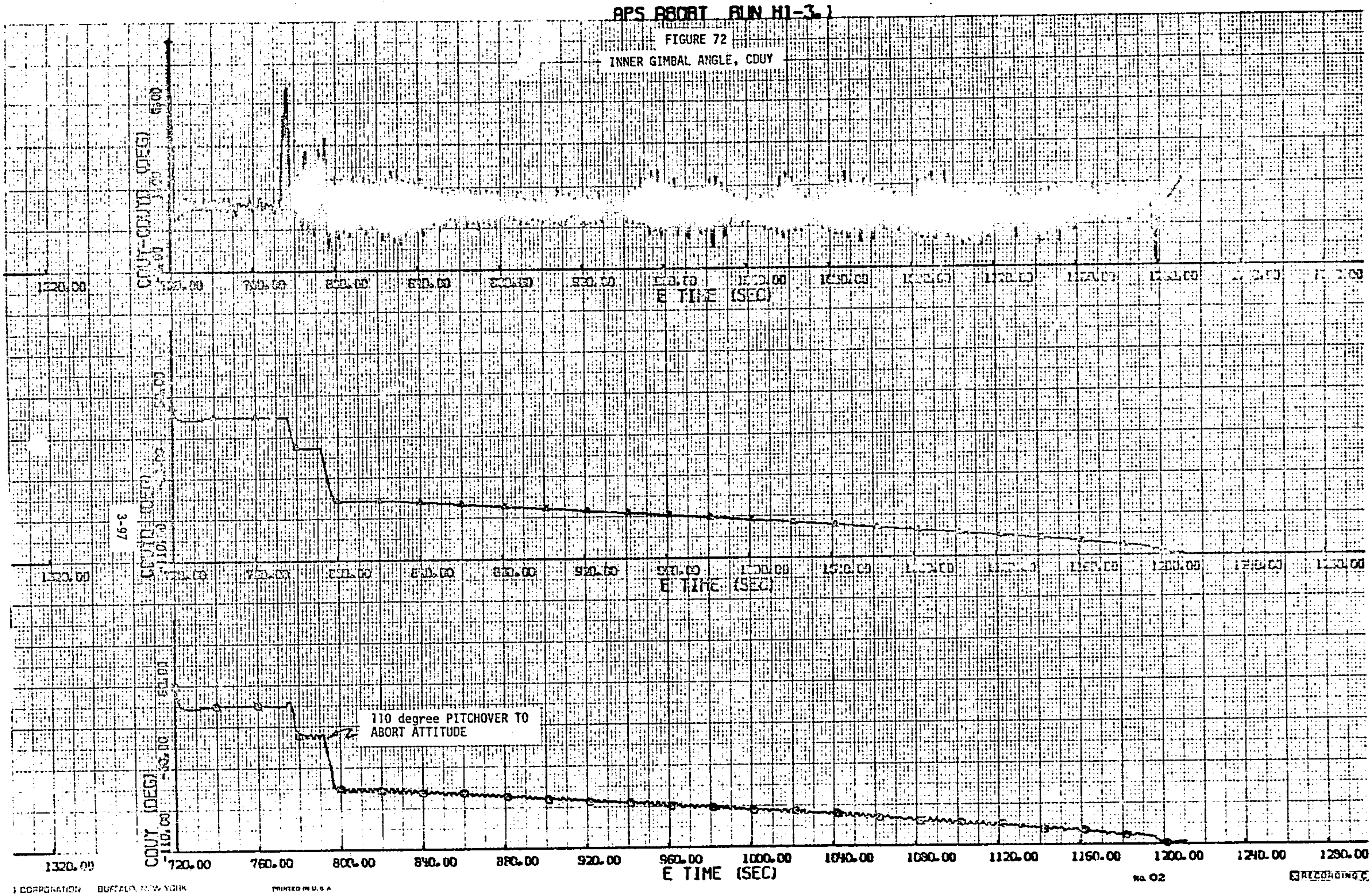
The residuals observed on the DSKY at APS cutoff via the noun 85 display were

VG(x) = -1.3

VG(y) = -0.7 ft/sec

VG(z) = +1.7

In conclusion, the results of this simulation indicate nominal DAP performance for a late APS abort from powered descent. Proper deadband sequencing at the inception of abort program P71 was verified.


APS ABORT RUN H1-3.1
FIGURE 72
INNER GIMBAL ANGLE, CDUY
CDUY-CDUYD (DEG)
CDUYD (DEG)
CDUY (DEG)
E TIME (SEC)
110 degree PITCHOVER TO
ABORT ATTITUDE
720.00
760.00
800.00
840.00
880.00
920.00
960.00
1000.00
1040.00
1080.00
1120.00
1160.00
1200.00
1240.00
1280.00
1320.00

APS ABORT RUN H1-3.1

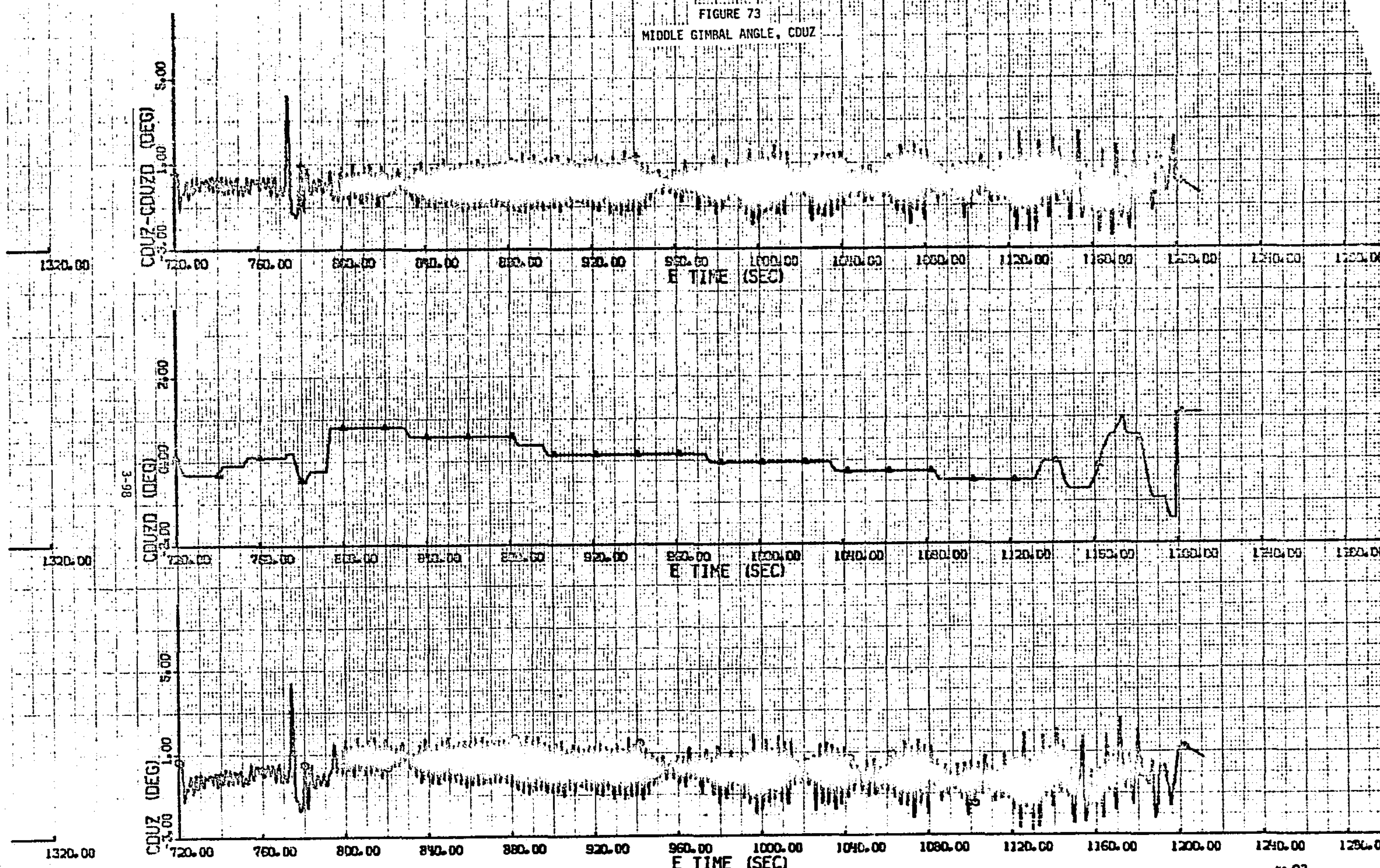
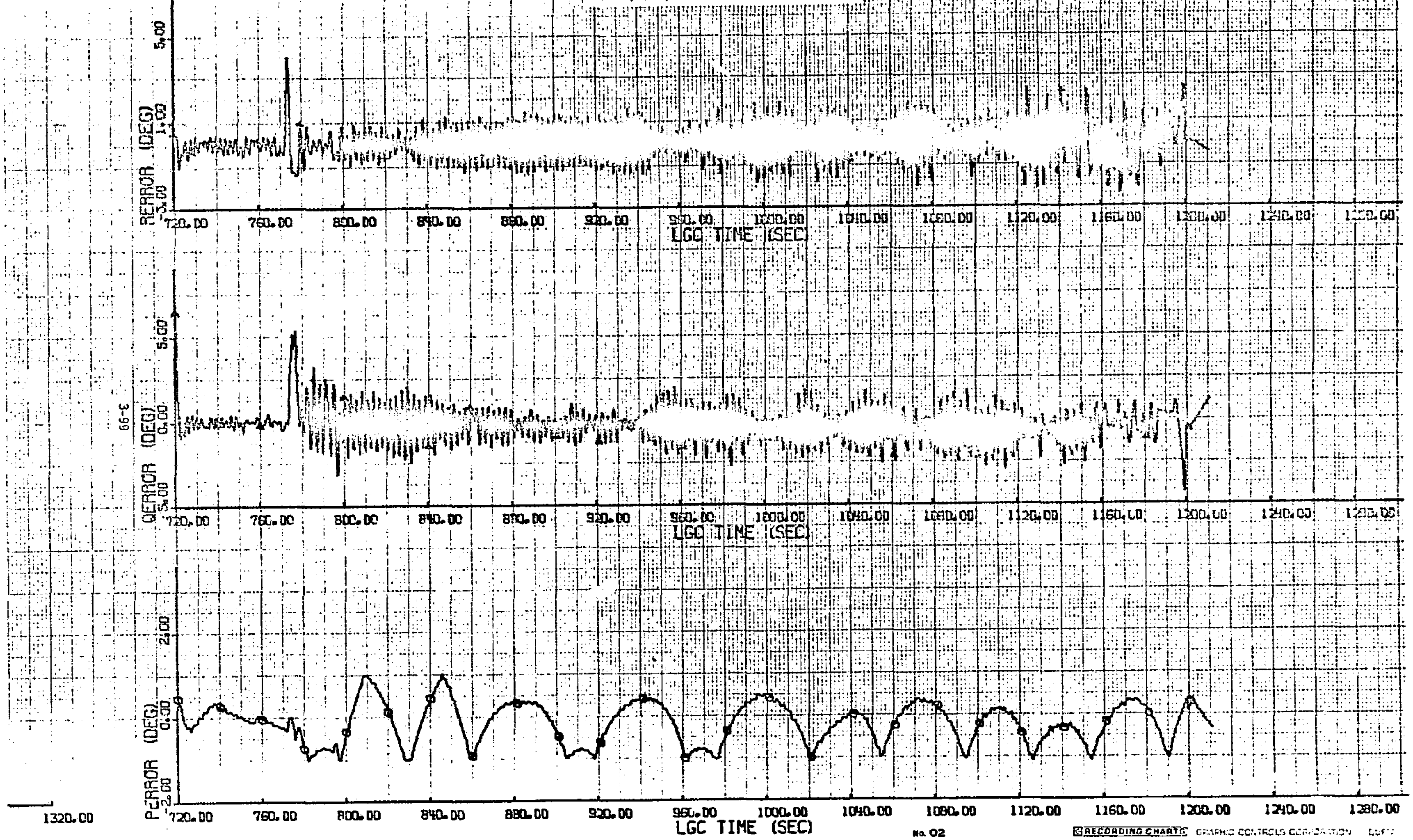


FIGURE 73
MIDDLE GIMBAL ANGLE, CDUZ

APS ABORT RUN H1-3.1

FIGURE 74

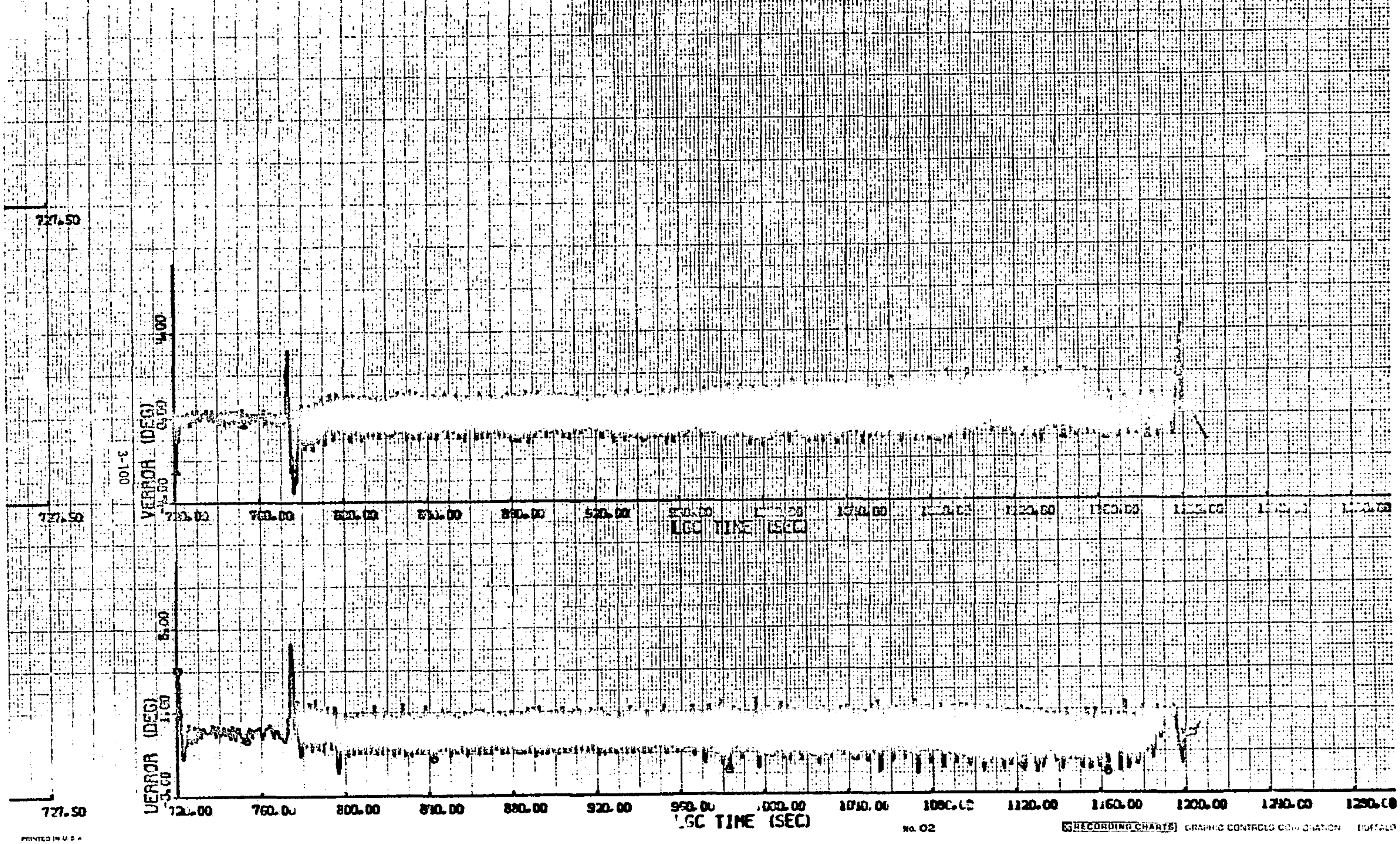
PITCH, YAW, AND ROLL ATTITUDE ERRORS



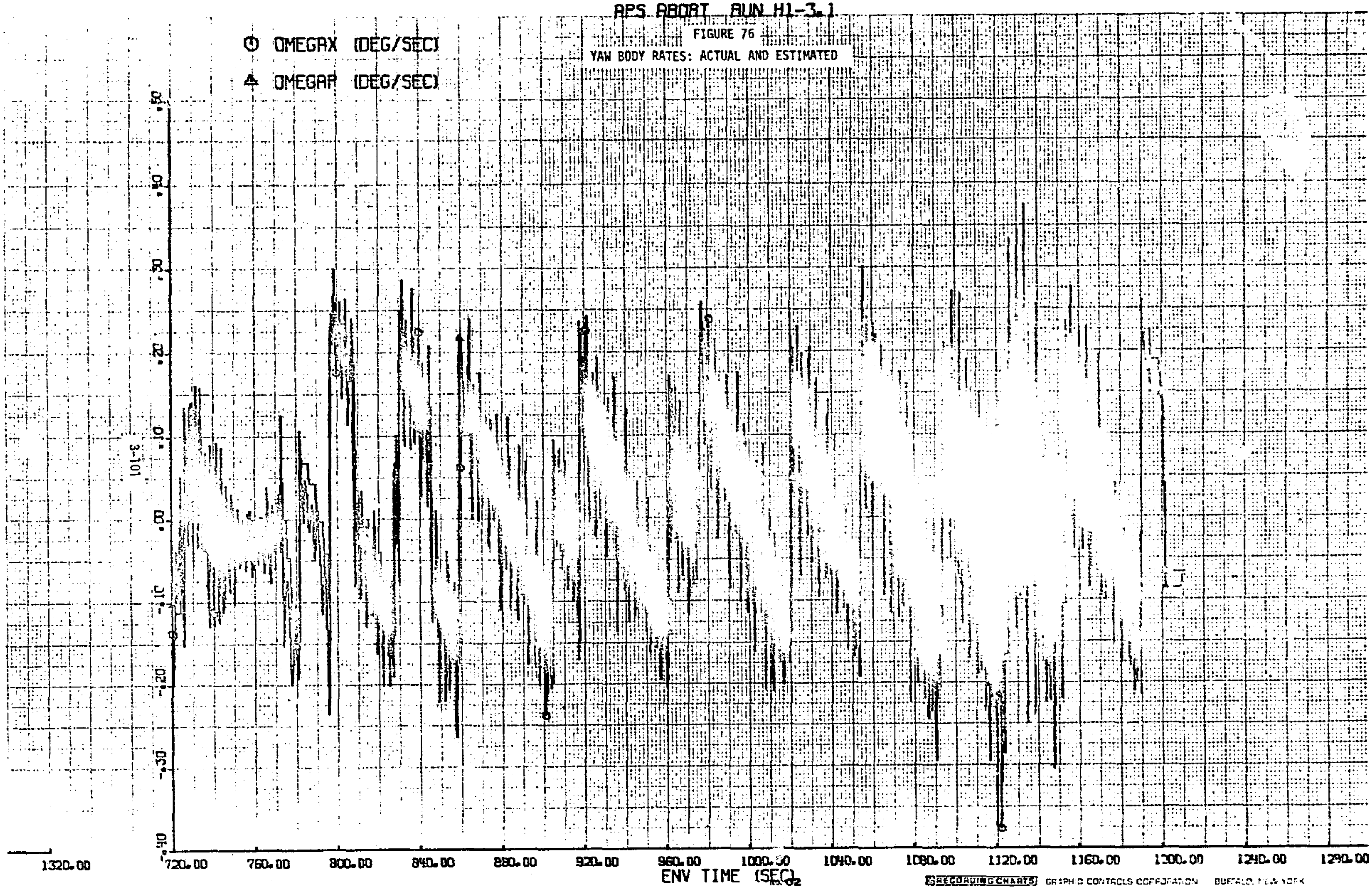
A-S ABORT RUN H1-3.1

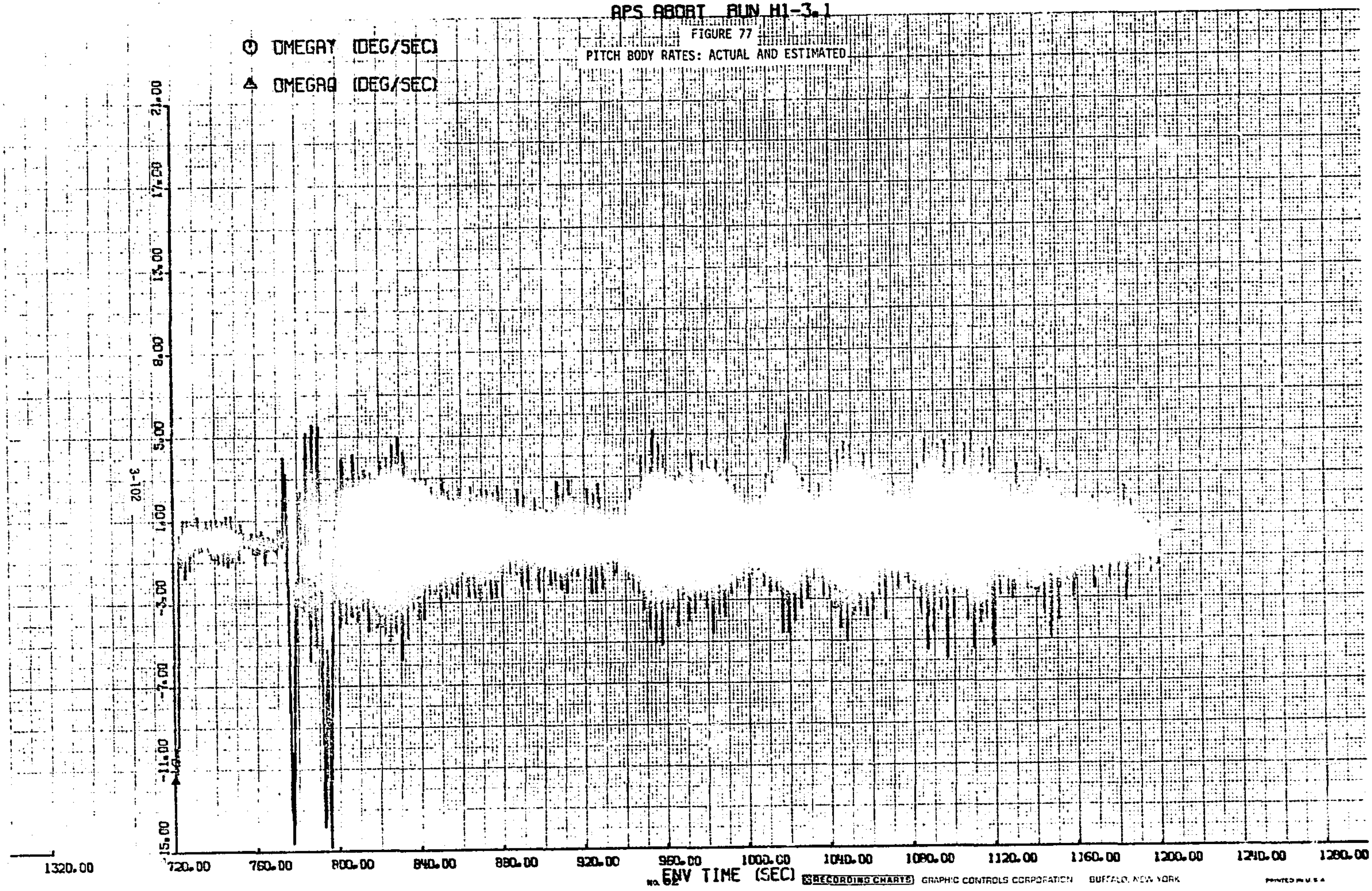
FIGURE 75

U', V' CONTROL AXES ATTITUDE ERRORS

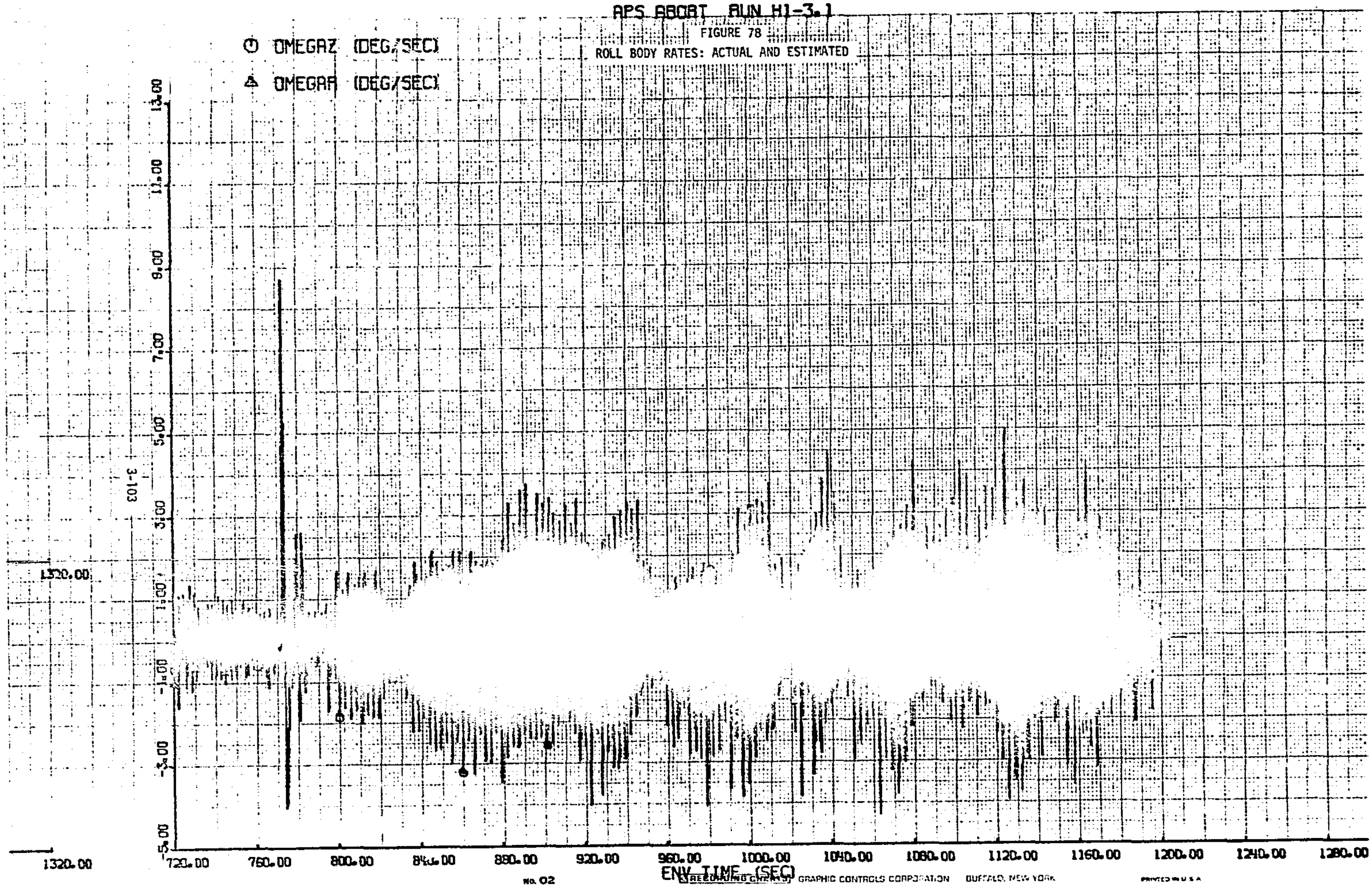


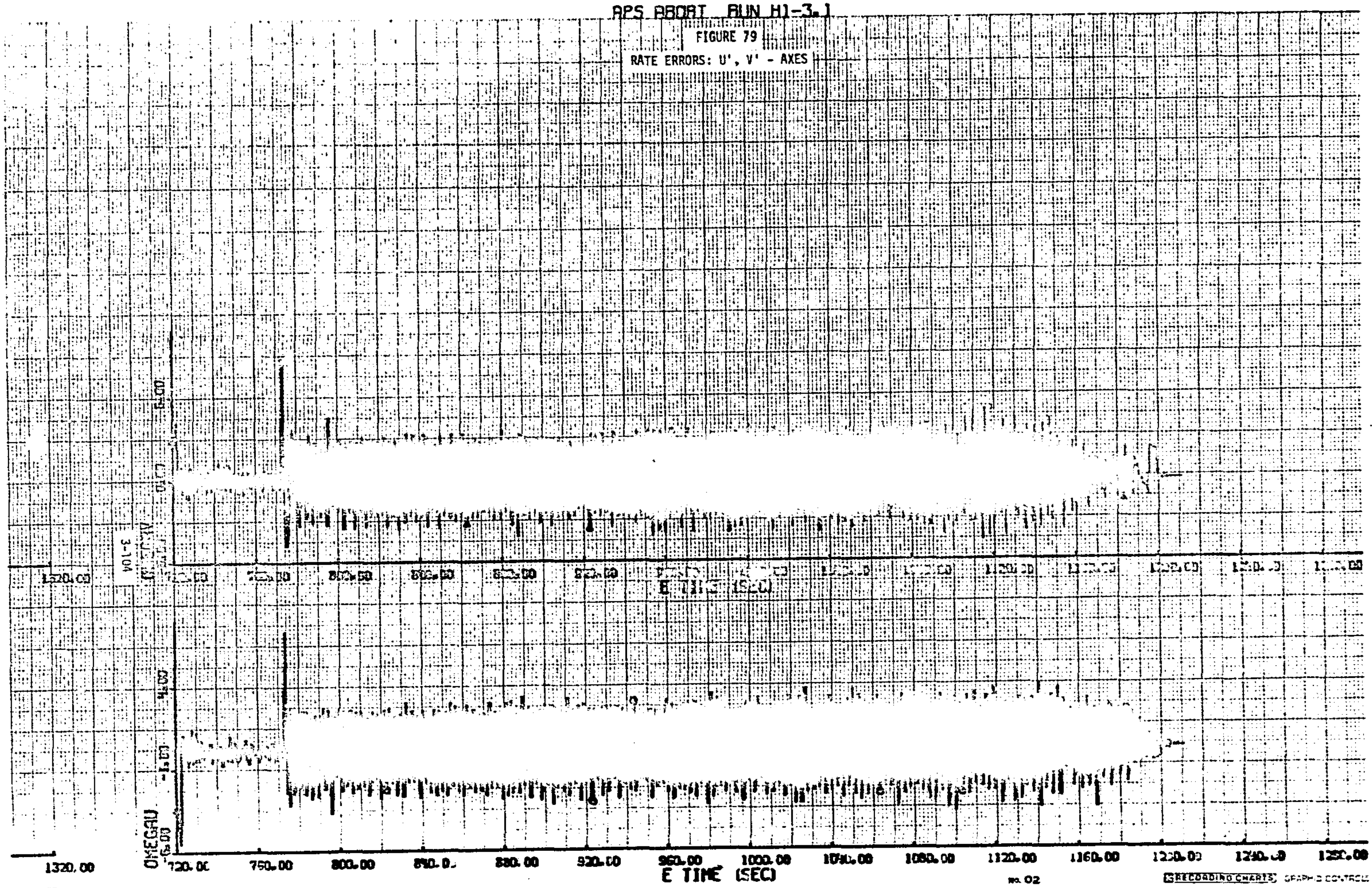
3-100


APS ABORT RUN H1-3.1
FIGURE 76
YAW BODY RATES: ACTUAL AND ESTIMATED
OMEGAX (DEG/SEC)
OMEGAP (DEG/SEC)
.50
.40
.30
.20
.10
.00
-.10
-.20
-.30
-.40
720.00
760.00
800.00
840.00
880.00
920.00
960.00
1000.00
1040.00
1080.00
1120.00
1160.00
1200.00
1240.00
1280.00
1320.00
ENV TIME (SEC)
RECORDING CHARTS GRAPHIC CONTROLS CORPORATION BUFFALO, NEW YORK



APS ABORT RUN H1-3.1
FIGURE 77
PITCH BODY RATES: ACTUAL AND ESTIMATED
OMEGAY (DEG/SEC)
OMEGAQ (DEG/SEC)
21.00
17.00
13.00
9.00
5.00
1.00
-3.00
-7.00
-11.00
-15.00
720.00
760.00
800.00
840.00
880.00
920.00
960.00
1000.00
1040.00
1080.00
1120.00
1160.00
1200.00
1240.00
1280.00
1320.00
ENV TIME (SEC)
RECORDING CHARTS GRAPHIC CONTROLS CORPORATION BUFFALO, NEW YORK


APS ABORT RUN H1-3.1
FIGURE 78
ROLL BODY RATES: ACTUAL AND ESTIMATED
OMEGAZ (DEG/SEC)
OMEGAA (DEG/SEC)
13.00
11.00
9.00
7.00
5.00
3.00
1.00
-1.00
-3.00
-5.00
720.00
760.00
800.00
840.00
880.00
920.00
960.00
1000.00
1040.00
1080.00
1120.00
1160.00
1200.00
1240.00
1280.00
1320.00
ENV TIME (SEC)
NO. 02
GRAPHIC CONTROLS CORPORATION BUFFALO, NEW YORK

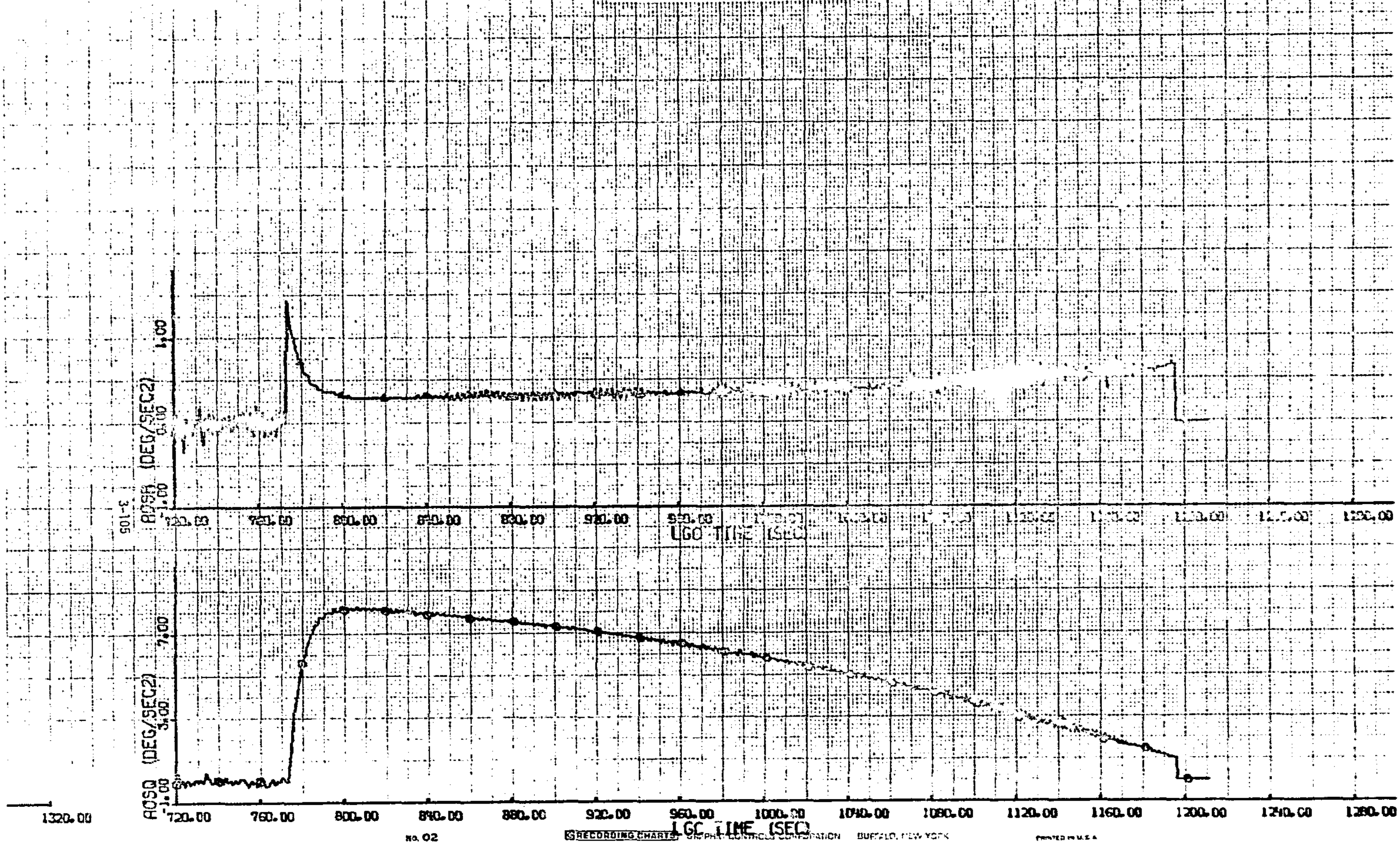


APS ABORT RUN H1-3.1
FIGURE 79
RATE ERRORS: U', V' - AXES
OMEGAU
E TIME (SEC)
720.00
760.00
800.00
880.00
920.00
960.00
1000.00
1080.00
1120.00
1160.00
1320.00

APS ABORT RUN H1-3.1

FIGURE 80

ESTIMATED BODY OFFSET ACCELERATIONS



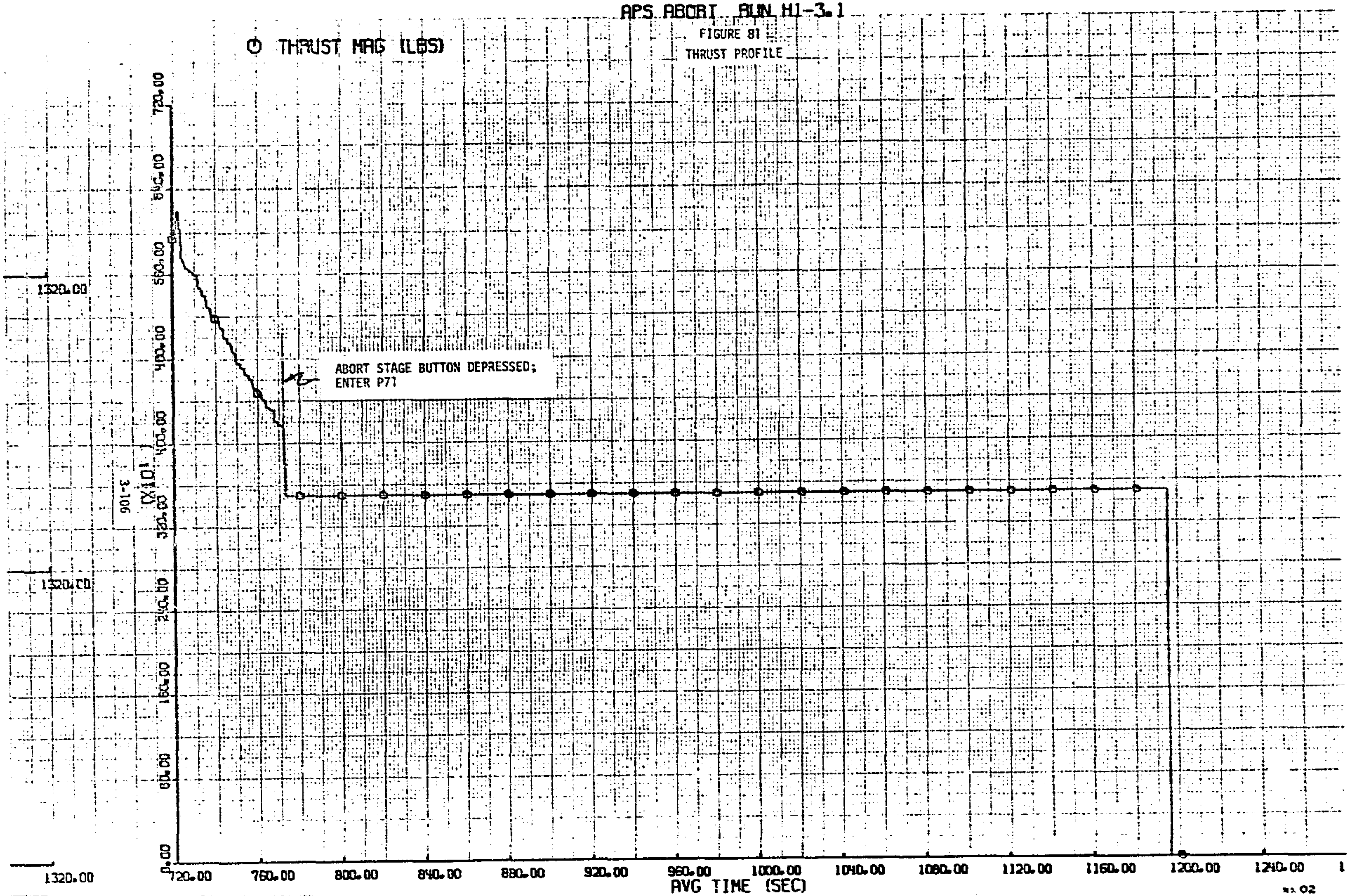


FIGURE 81
THRUST PROFILE

APS ABORT RUN H1-3.1

FIGURE 82

RCS ACTIVITY

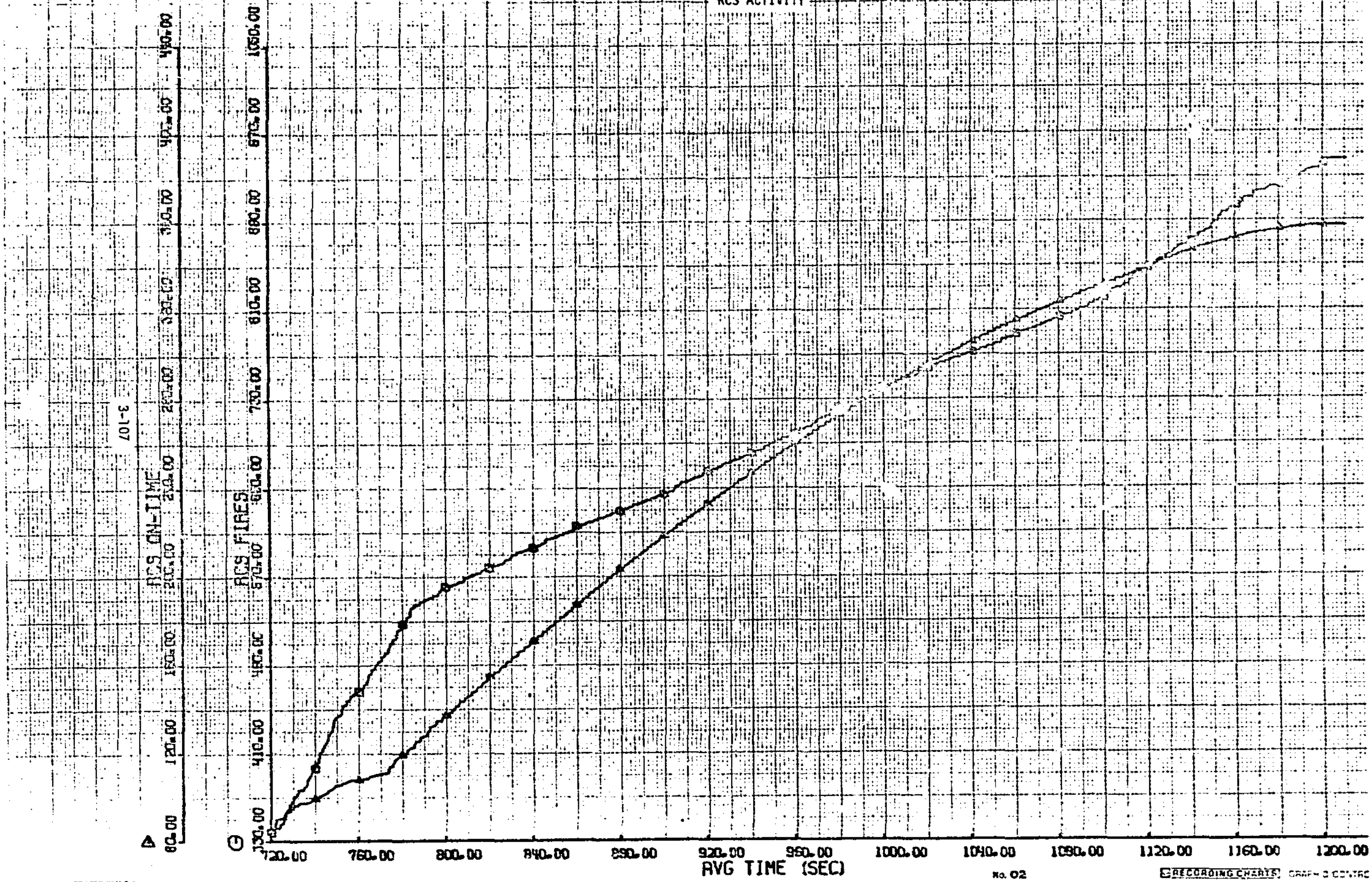


TABLE 3
KEY VARIABLES

Description	Variable	Run Number H1 - 1.5	H1 - 3.0	H1 - 3.1
Maximum Attitude Errors (deg) (Time of Occurrence - sec)	PERROR	-7.5 (550)	-1.00 (inside deadband)	-1.00 (inside deadband)
	QERROR	-6.5 (725)	-6.75 (776)	+5.25 (776)
	RERROR	1.6 (550)	+3.30 (852)	+4.00 (773)
	UERROR	4.7 (728)	-5.2 (784)	+4.3 (774)
	VERROR	-4.4 (728)	+6.4 (784)	-3.6 (776)
Maximum Rates (deg/sec) (Time of Occurrence - sec)	OMEGAP	-10.5 (552)	-1.10 (780)	+0.375 (1134)
	OMEGAQ	-12.1 (728)	-11.8 (788)	-14.8 (796)
	OMEGAR	2.1 (550)	+8.1 (852)	+8.7 (772)
	OMEGAU	6.1 (728)	+6.75 (784)	+7.25 (774)
	OMEGAV	-5.9 (725)	-6.75 (784)	+7.25 (774)
Average Peak-to-Peak Attitude Errors (deg)	QERROR	2.5*	2.6**	3.75**
	RERROR	2.4*	2.8**	3.2**
	UERROR	2.0	2.0**	2.0**
	VERROR	2.0	2.0**	2.0**

*The above values were taken at peak amplitudes and were not necessarily sustained oscillations.

**These values pertain to the ascent limit cycle behavior.

TABLE 3 (Continued)
KEY VARIABLES

Description	Variable	Run Number		
		H1 - 1.5	H1 - 3.0	H1 - 3.1
Average Peak-to-Peak Rates (deg/sec)	OMEGAQ	2.3*	8.0**	8.6**
	OMEGAR	2.25*	6.0**	6.5**
	OMEGAU	2.0*	5.5**	5.5**
	OMEGAV	2.5*	5.5**	5.3**

*The above values were taken at peak amplitudes and were not necessarily sustained oscillations.

**These values pertain to the ascent limit cycle behavior.

TABLE 4
RCS ACTIVITY SUMMARY
(End of Ullage to Touchdown or Cutoff)

Jet No.	Run H1-1.5		Run H1-3.0		Run H1-3.1	
	Jet On Time (sec)	No. of Fires	Jet On Time (sec)	No. of Fires	Jet On Time (sec)	No. of Fires
1	8.176	71	10.838	59	8.639	55
2	8.659	81	12.672	70	11.024	72
3	1.167	12	3.322	9	3.055	8
4	0.874	12	3.097	19	3.137	20
5	7.648	64	13.566	62	10.596	53
6	7.770	69	132.065	200	139.734	229
7	2.843	12	1.198	22	1.026	22
8	2.638	9	0.871	7	0.870	7
9	8.659	81	11.549	66	7.949	52
10	8.164	70	113.658	223	119.071	240
11	1.167	12	3.322	9	3.055	8
12	0.873	12	3.097	19	3.137	20
13	7.759	68	12.867	51	10.096	48
14	7.696	68	13.704	62	11.851	64
15	2.843	12	1.198	22	1.026	22
16	2.638	9	0.871	7	0.870	7
Total On Time of All Jets (sec)	79.574		337.895		335.136	
Total No. of Fires	662		907		927	
Total Propellant (lbs)	30.593		126.950		125.983	

3.8 DESCENT WITH UNDETECTED FAILURE OF DPS GIMBALS; RUNS H1-1.6A, H1-1.6B, AND H1-1.6D

Test Description

This test is composed of a set of three simulations of powered descent under conditions of various DPS gimbal failures. The gimbal failures are introduced in the Environments Section of the B-B-B Simulator and are undetected by the LGC. All failures are initiated at 300 seconds after ignition during a nominal descent sequence. The set of runs is made up of

Run No.	Mistrim at time of gimbal failure
H1-1.6A	No mistrims in either axes
H1-1.6B	1^{o} mistrim in JPY, no mistrim in JPZ
H1-1.6D	1^{o} mistrim in JPZ, no mistrim in JPY

Test Objective

The primary objective of this test case was to observe the spacecraft response under the conditions of DPS gimbal failures and to evaluate and discuss response characteristics which are most definitive in discerning types and degrees of gimbal failures. A secondary objective is to evaluate DAP performance in continuing and completing powered descent with early DPS gimbal failures.

Initialization Data

All three of the simulations reported in this section were made as checkpoint restarts from the nominal descent Run H1-1.0 which was reported in Section 3.1. Consequently, the initialization data for these runs are identical to those used for Run H1-1.0. Refer to Section 3.1 for exact values. The simulations reported here begin at TIME = 510.00 seconds (ignition +300 seconds). The initial body rates and attitude errors are

PERROR		-1.0	
QERROR	=	0.0	deg
RERROR		+0.2	

and

OMEGAX	0.0	
OMEGAY	+0.4	deg/sec
OMEGAZ	+1.0	

Timeline

The following is a list of major events and their times of occurrence for the three simulations.

	Event	Time-Seconds H1-1.6A	H1-1.6B	H1-1.6D
1)	In P63 and nominal descent	510.00	510.00	510.00
2)	Both DPS gimbals failed (undetected by LGC)	512.023	512.023	512.023
3)	Throttle-down	≈596.00	≈596.00	≈596.00
4)	Enter Visibility Phase, Program P64	727.00	717.00	717.00
5)	Enter Automatic Terminal Landing Phase, Program P65	859.00	861.00	- - -
6)	Touchdown Confirmed	906.39	907.19	- - -

Results

The simulated DPS gimbal failures were implemented in the Environments Section of the B-B-B Simulator. This constitutes an undetected hardware failure in that the actual DAP, GTS control law and state estimator, has no knowledge of the failures and is not compensated in any way.

The DPS gimbals were frozen at TIME = 512.0 seconds which is approximately 300 seconds after ignition. Disturbances due to thrust vector misalignments, at the time of gimbal failure, would hopefully be small enough to remain within the realm of RCS control effectiveness. Under these conditions the LM DAP would be expected to perform in a fashion similar to control during ascent burns. RCS limit cycling resulting from the constant body torques generated from thrust vector misalignments should be observed.

Run H1-1.6D which consists of pitch and roll gimbal failures plus an initial 1.0 degree mistrim in the roll gimbal did not achieve a complete descent sequence. Because of problems in the landing radar del in the B-B-B Simulator, diagnostic errors were generated which terminated the run at TIME = 826.65 seconds. The problem is connected with the simulator and not the flight program. Even though a successful landing was not achieved, it is felt that a sufficiently long time segment with good data was obtained to warrant reporting here.

Table 5 contains a list of key variables, their magnitudes, and times of occurrence. Table 6 represents the RCS activity summary for each of the three runs on an individual jet basis. Figures 82 thru 110 present the plots of various variables of interest. The plots were made from data sampled every fifth DAP cycle which corresponds to 0.5 seconds between data points.

The spacecraft response for all three simulations was essentially of the same character. The three runs are discussed in a composite fashion here. Attitude errors as shown in Figures 84, 93, and 105 are biased around the deadbands. Phase planes presented in Figures 98 and 99 show the nature of the observed RCS limit cycle. The vehicle response seen here is essentially the same behavior seen in long ascent burns. At the end of long ascent burns discussed in References 2 and 5 the offset acceleration becomes small as the c.g. approaches and crosses the body axes. Under these conditions of small offset accelerations, the phase plane trajectories hang-up on the deadbands. This results in a small amplitude and unsymmetrical limit cycle. These same conditions are observed from the results obtained for the gimbal failure conditions. Even with 1 degree mistrims at the time of gimbal failure, offset accelerations are sufficiently small to produce the small amplitude and attitude-error-biased limit cycle. The spacecraft response from an overall view was extremely smooth, and fuel slosh dynamics, while present (Refer to Figures 94, 95, and 96), are significantly reduced in amplitude in comparison with results obtained in the nominal descent case. (See Section 3.1). Estimated body rates, for example as shown in Figures 86, 95, and 107, include a small steady-state error. This steady-state rate error results from the state estimators prediction of the effect of DPS gimbal activity which never occurs. (The GTS control law continues to function after the gimbal failures). The effect of the steady state rate error should be small in that it simply displaces the limit cycle above or below the attitude error axis on the phase plane. As the powered descent continues, the small RCS limit cycle centers around +1.8 degrees (deadband + FLAT). After P64 is reached, the limit cycle settles around +1.1 degrees (0.3 degree deadband + FLAT).

The time histories of the gimbal angles are presented in Figures 88, 89, 100, 101, 109, and 110. For comparison, the mean gimbal angles for the nominal descent Run H1-1.0 are plotted as dashed lines on these figures for the same time period. The difference between the two curves indicates the degree of thrust misalignment present during the remainder of the descent.

Table 6 presents a summary of the RCS activity for the three runs an individual jet basis. Figures 91, 103, and 112 show the time histories of accumulated total jet on-time and accumulated total number of jet firings. These curves were generated from data obtained from the environments portion of the B-B-B Simulator. Over the time interval of interest (TIME - 510.00 seconds to touchdown), the average firing rate of the RCS was 2.22 fires/sec for the nominal descent Run H1-1.0 (See Section 3.1). In Run H1-1.6A for which both gimbals were frozen with essentially no mistrim, the average firing rate varied from 6.33 fires/sec to 6.84 fires/sec. In Run H1-1.6B the pitch gimbal was mistrimmed 1 degree at the time both gimbal were failed, and the average firing rate increased to 13.45-13.95 fires/sec. In Run H1-1.60 the roll gimbal was initially mistrimmed 1 degree at the time of failure and the resulting average firing rate was 13.4-13.3 fires/sec. Interestingly, initial 1 degree mistrims in either gimbal axis at the time of failure resulted in an approximately 50% increase in the average firing rate relative to the case with no mistrims. This increase in firing rate is essentially constant over the time interval of interest.

With regard to propellant usage, the following numbers were generated. In the nominal descent Run H1-1.0, the average propellant consumption rates varied from 0.0540 lbs/sec to 0.0462 lbs/sec. With no mistrims initially at the time the gimbal were failed (H1-1.6A), the average consumption rate was 0.0940-0.0945 lbs/sec. With an initial 1 degree mistrim in the pitch gimbal the average consumption rate increased dramatically to 0.528-0.319 lbs/sec. With the initial 1 degree mistrim in the roll gimbal the average consumption rate were 0.446-0.391 lbs/sec. For the number stated in the above discussion with regard to average firing rates and average propellant consumption rates, the first value stated is generally the value observed during P63. The second number stated usually pertains from the time of (P64) automatic pitchover until touchdown.

Of interest with regard to RCS activity is the duty cycle of the downward firing jets, some of which are thermally constrained. The numbers presented here are for a duty cycle measure defined as the total accumulated on-time for jets 2, 6, 10 and 14 divided by the length of the time interval considered. The time interval was usually taken as the time from gimbal failure until lunar touchdown (except for H1-1.6D). The following percentages were obtained.

Run	Duty Cycle
H1-1.0 (nominal descent)	9.15%
H1-1.6A	14.2%
H1-1.6B	67.1%
H1-1.6D	65.0%

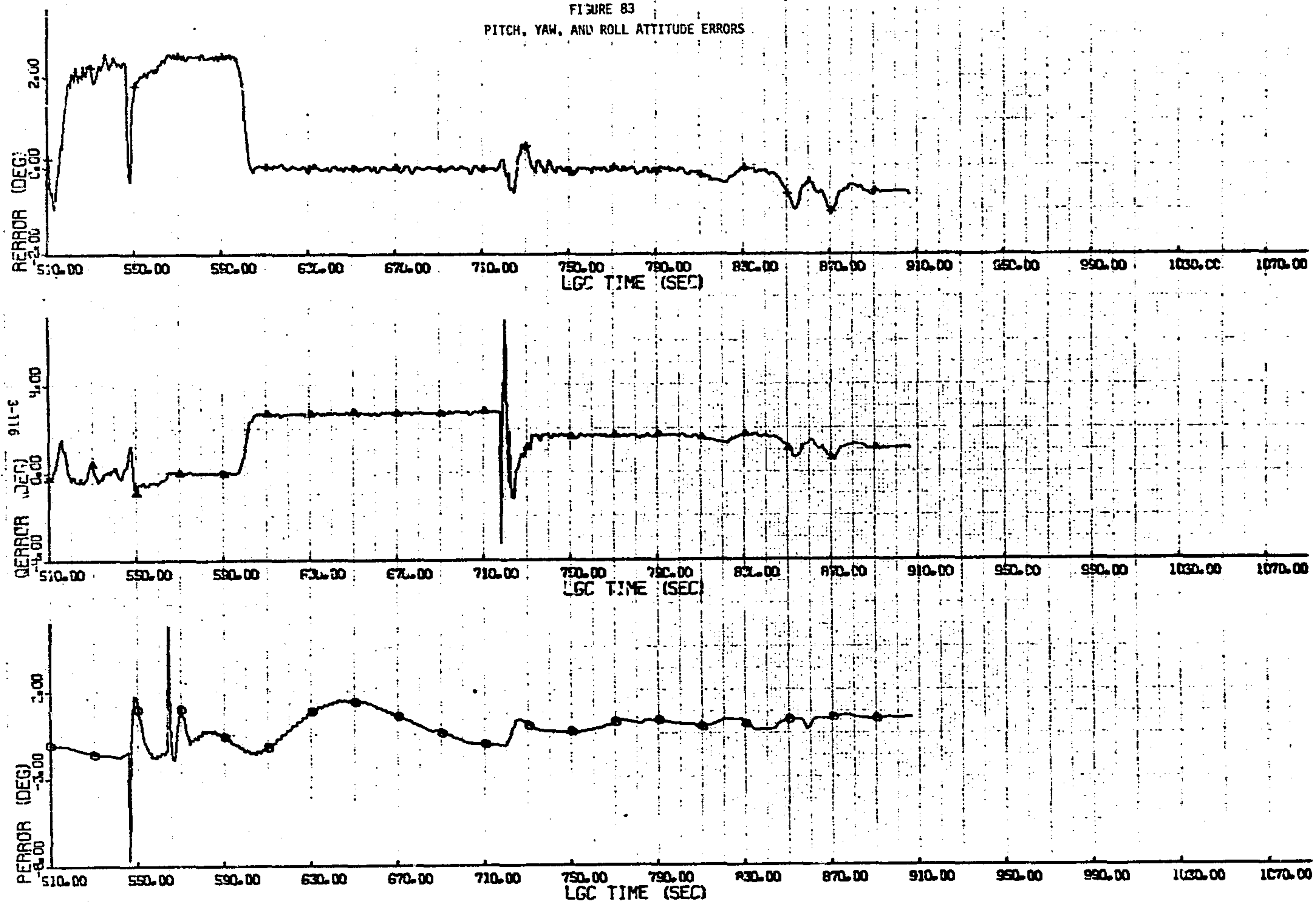
The extreme sensitivity to initial mistrims, while expected, is still significant. Although spacecraft stability is maintained, the increase in propellant consumption and RCS duty cycles for the mistrimmed cases may be problems. The RCS propellant reserves could nominally handle the excess expenditure but the duty cycle approaches the latest available constraint of 50% over 400 seconds.

In conclusion, under the conditions of gimbal failure tested the spacecraft response was smooth and fuel slosh effects were reduced from that seen in the nominal descent case. Small amplitude RCS limit cycles around the deadbands resulted from the small offset accelerations due to thrust misalignments. RCS duty cycle increases substantially with gimbal failure. Further increases in duty cycle result from initial mistrim at the time the DPS gimbals are failed. Observation of RCS duty cycle is a good measure of the occurrence of gimbal failures but it is doubtful how effective it would be in evaluating the nature (frozen or runaway gimbals) of gimbal failures.

LUNAR LANDING RUN H1-1.6 A

FIGURE 83

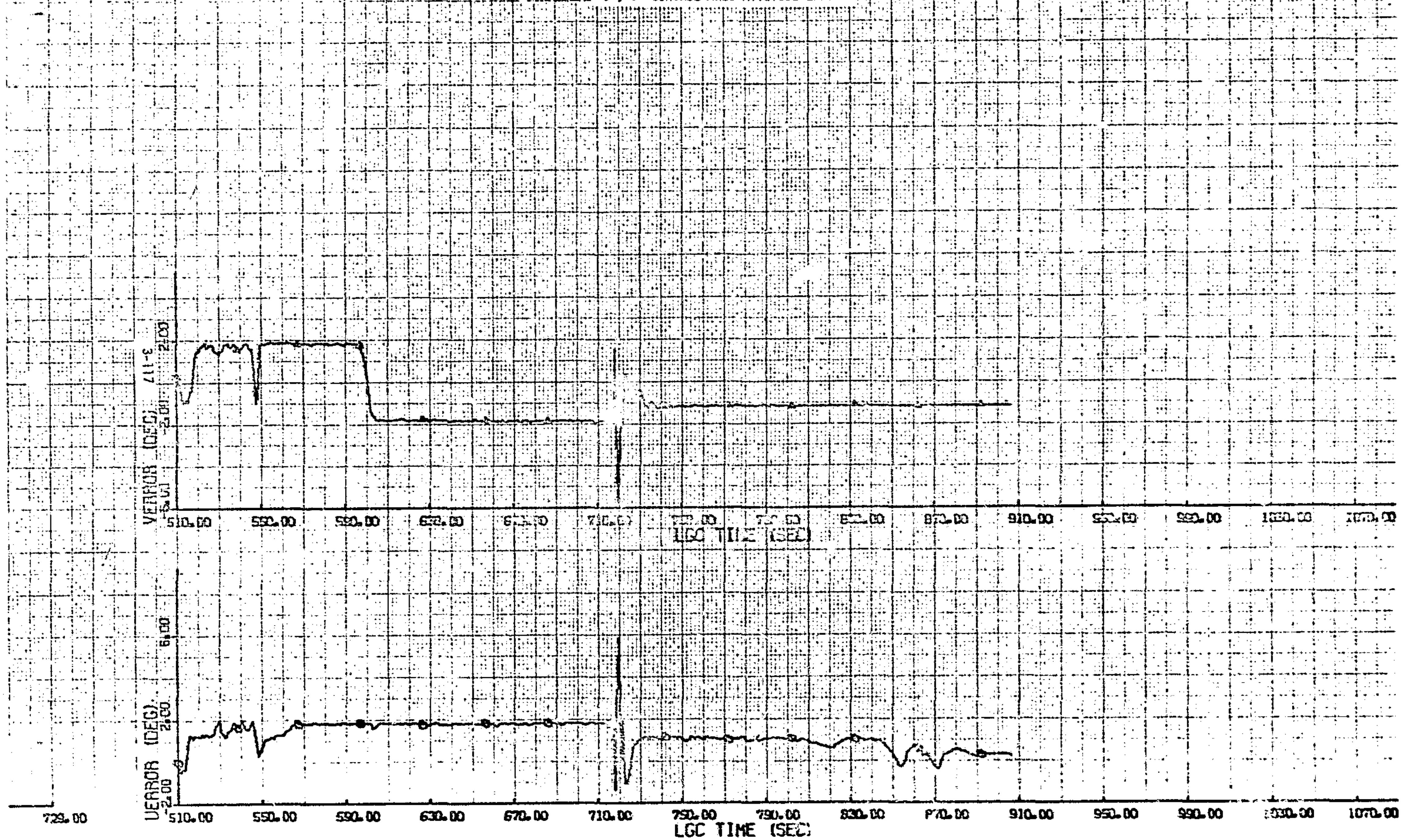
PITCH, YAW, AND ROLL ATTITUDE ERRORS



LUNAR LANDING RUN H1-1.6 A

FIGURE 84

U', V' CONTROL AXES ATTITUDE ERRORS

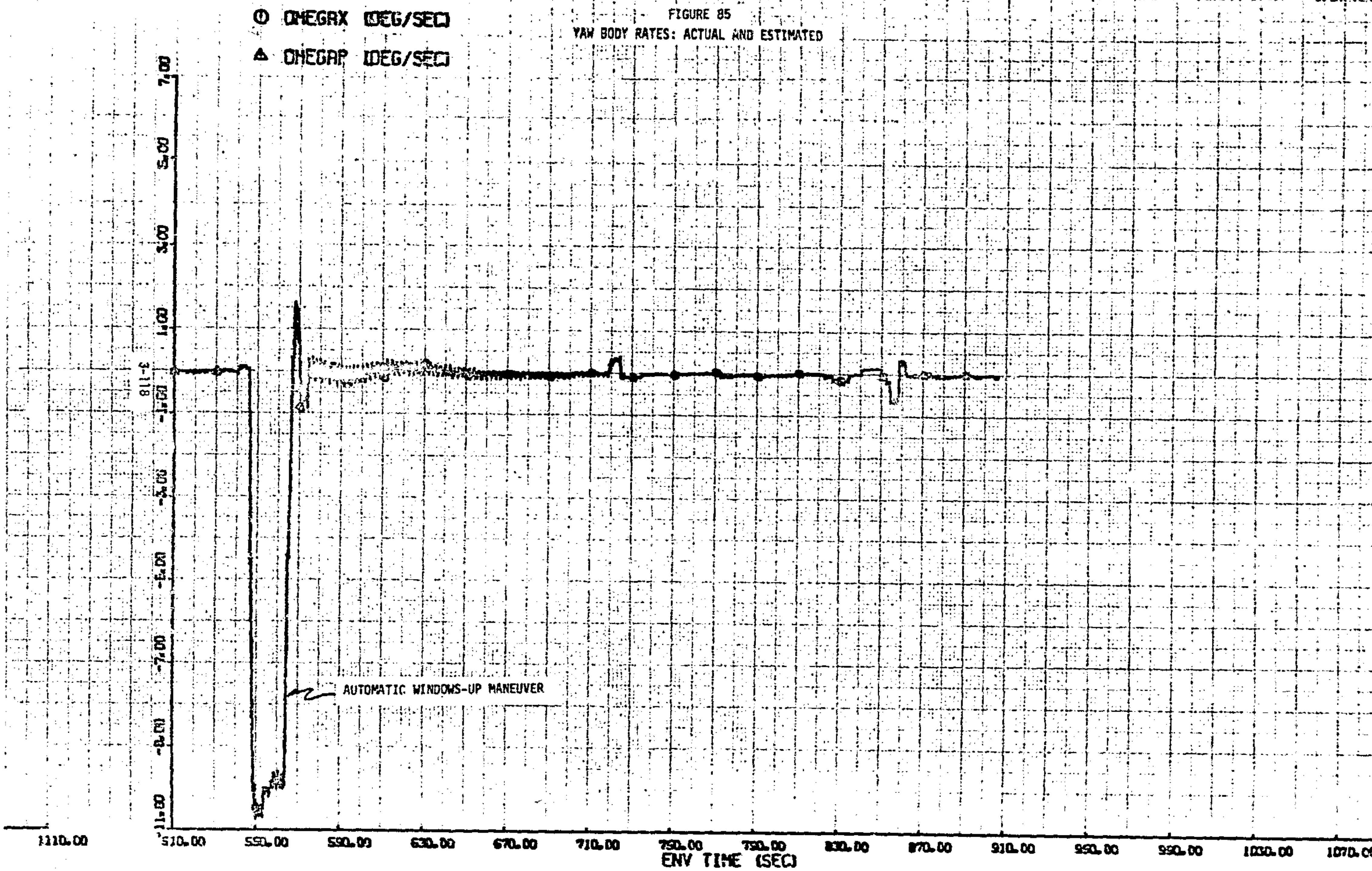


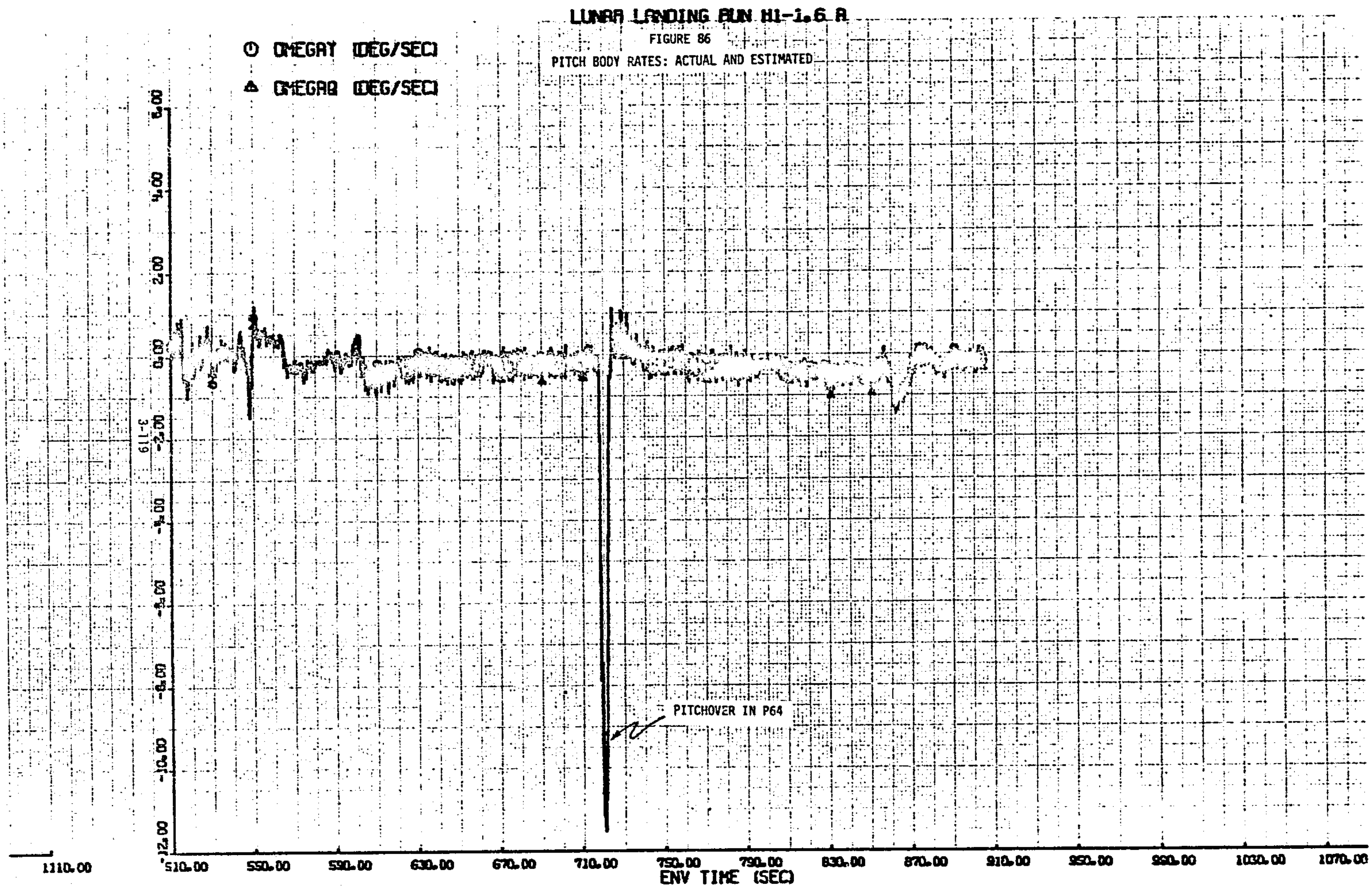
3-117

LUNAR LANDING RUN H1-1.6 A

FIGURE 85

YAW BODY RATES: ACTUAL AND ESTIMATED



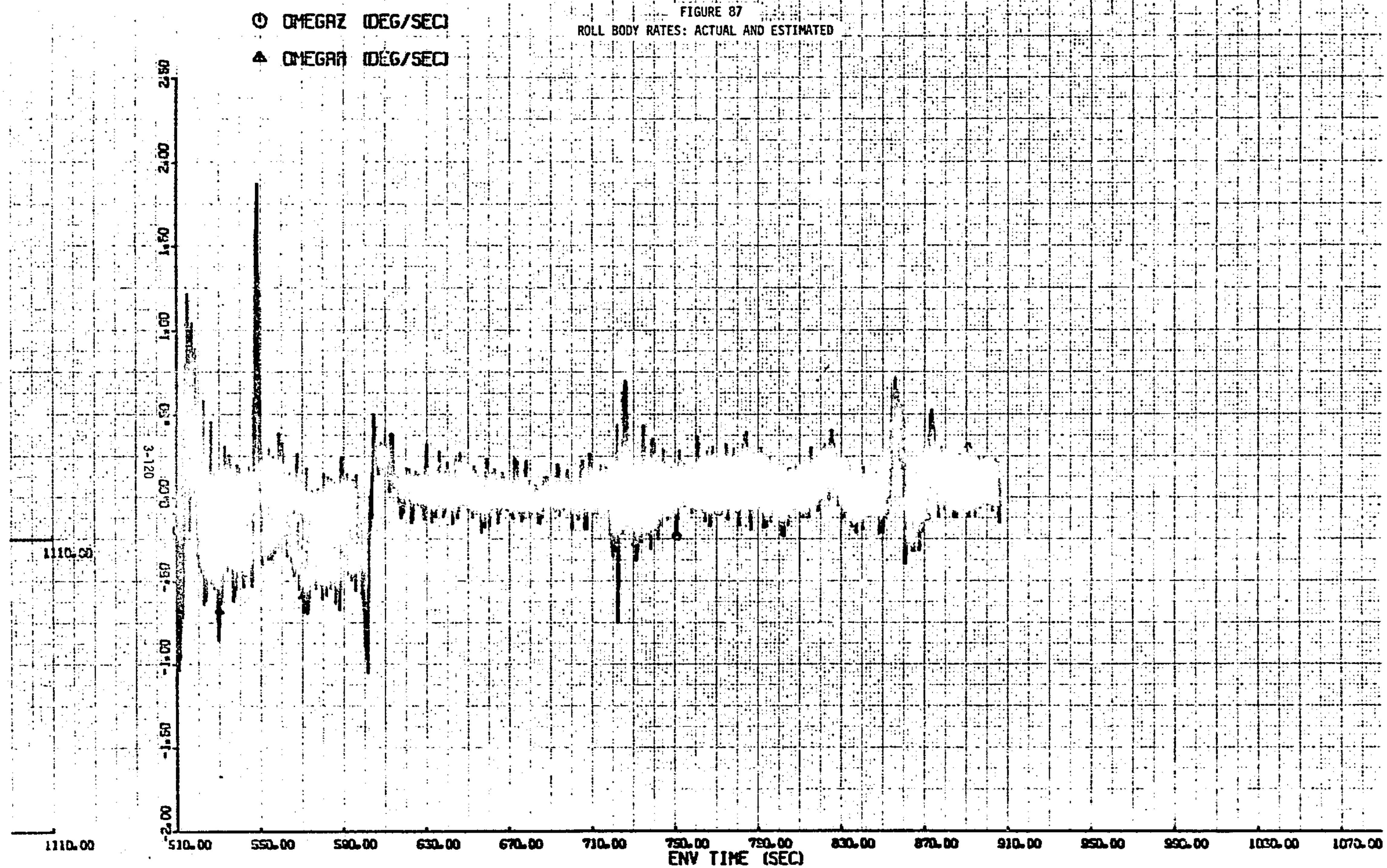


LUNAR LANDING RUN H1-1.6 A
FIGURE 86
PITCH BODY RATES: ACTUAL AND ESTIMATED
⊙ OMEGAY (DEG/SEC)
△ OMEGAQ (DEG/SEC)
6.00
4.00
2.00
0.00
-2.00
-4.00
-6.00
-8.00
-10.00
-12.00
PITCHOVER IN P64
510.00
550.00
590.00
630.00
670.00
710.00
750.00
790.00
830.00
870.00
910.00
950.00
990.00
1030.00
1070.00
1110.00
ENV TIME (SEC)

LUNAR LANDING RUN H1-1.6 A

FIGURE 87

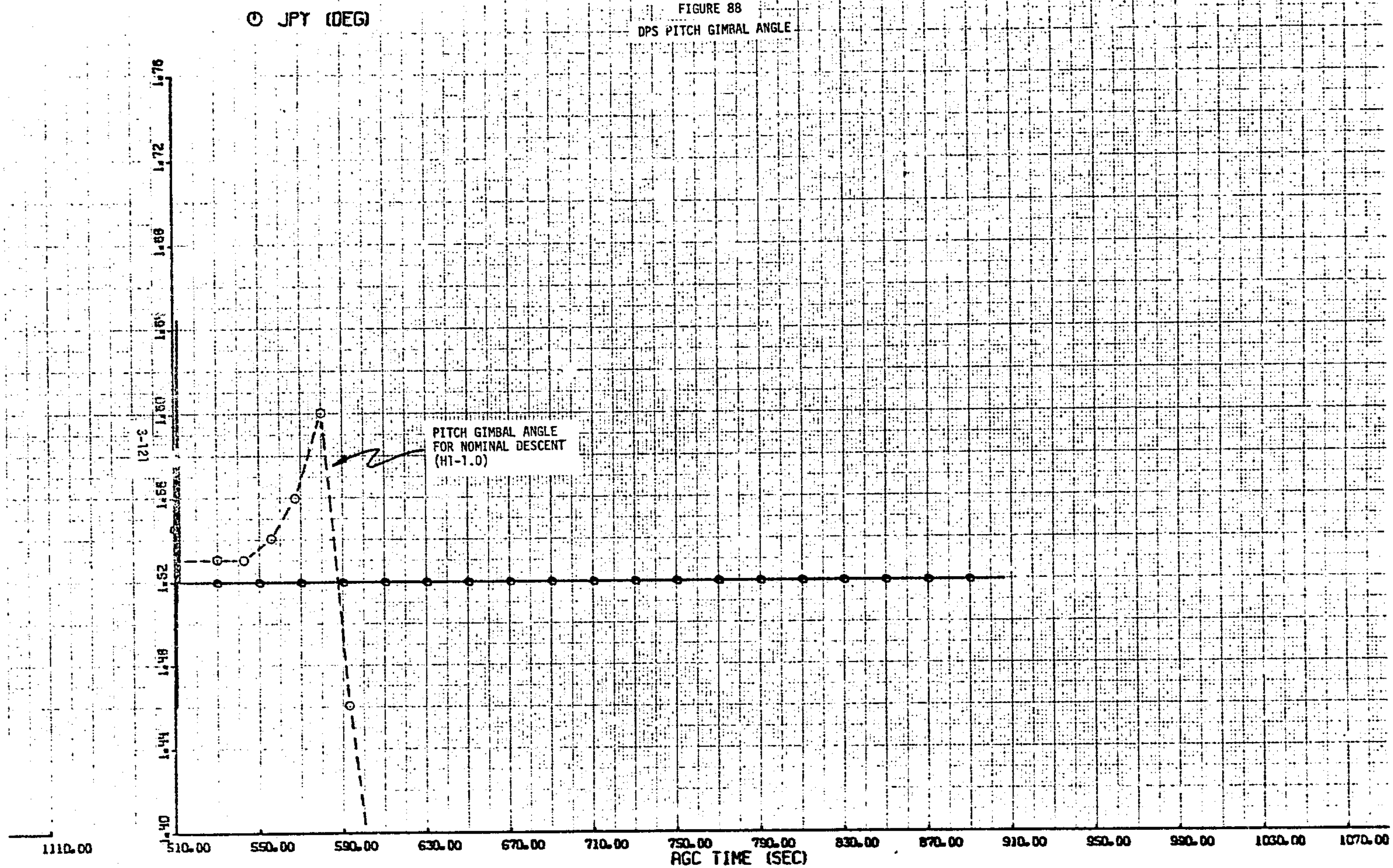
ROLL BODY RATES: ACTUAL AND ESTIMATED



LUNAR LANDING RUN H1-1.6 A

FIGURE 88

DPS PITCH GIMBAL ANGLE



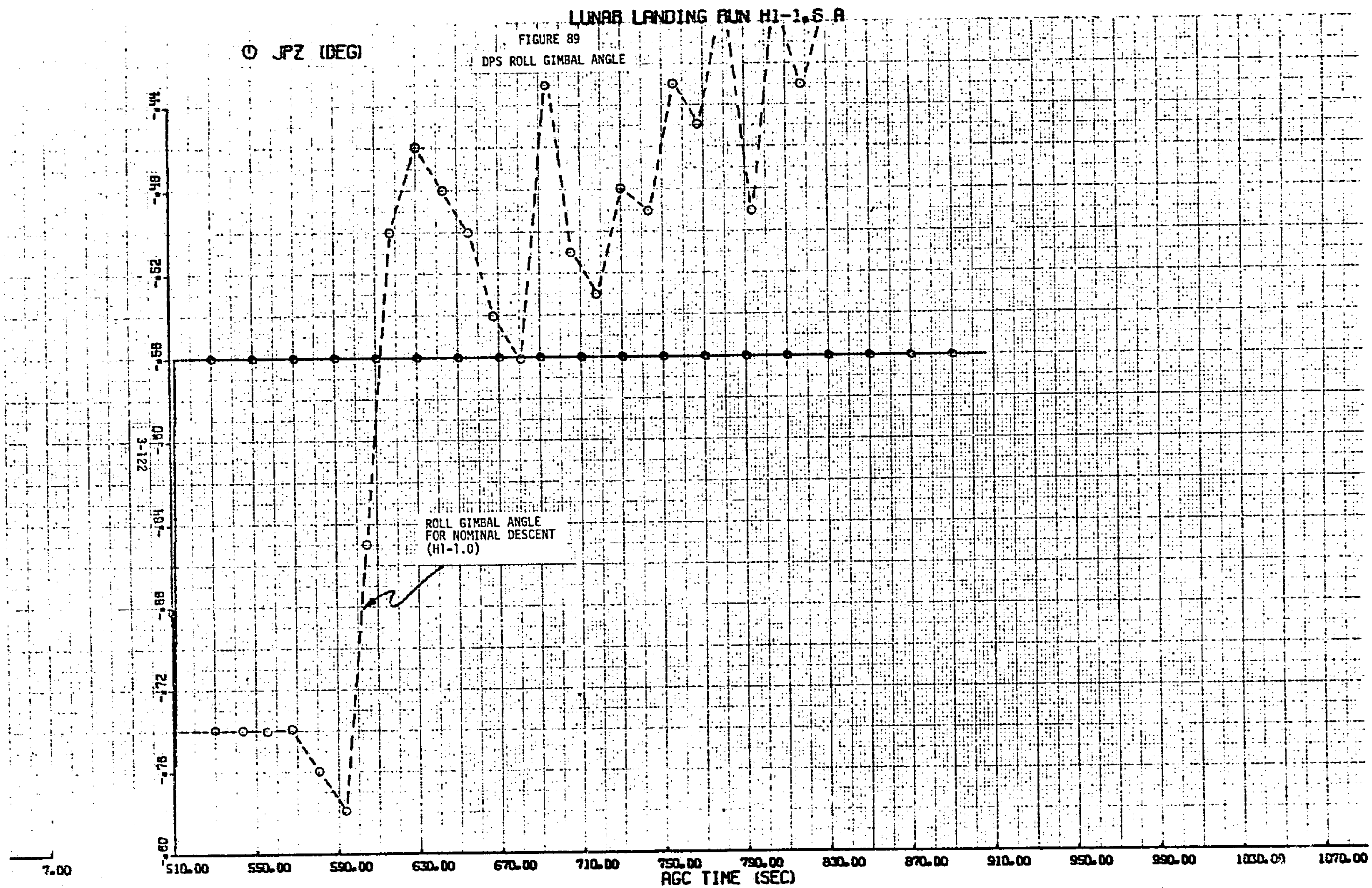
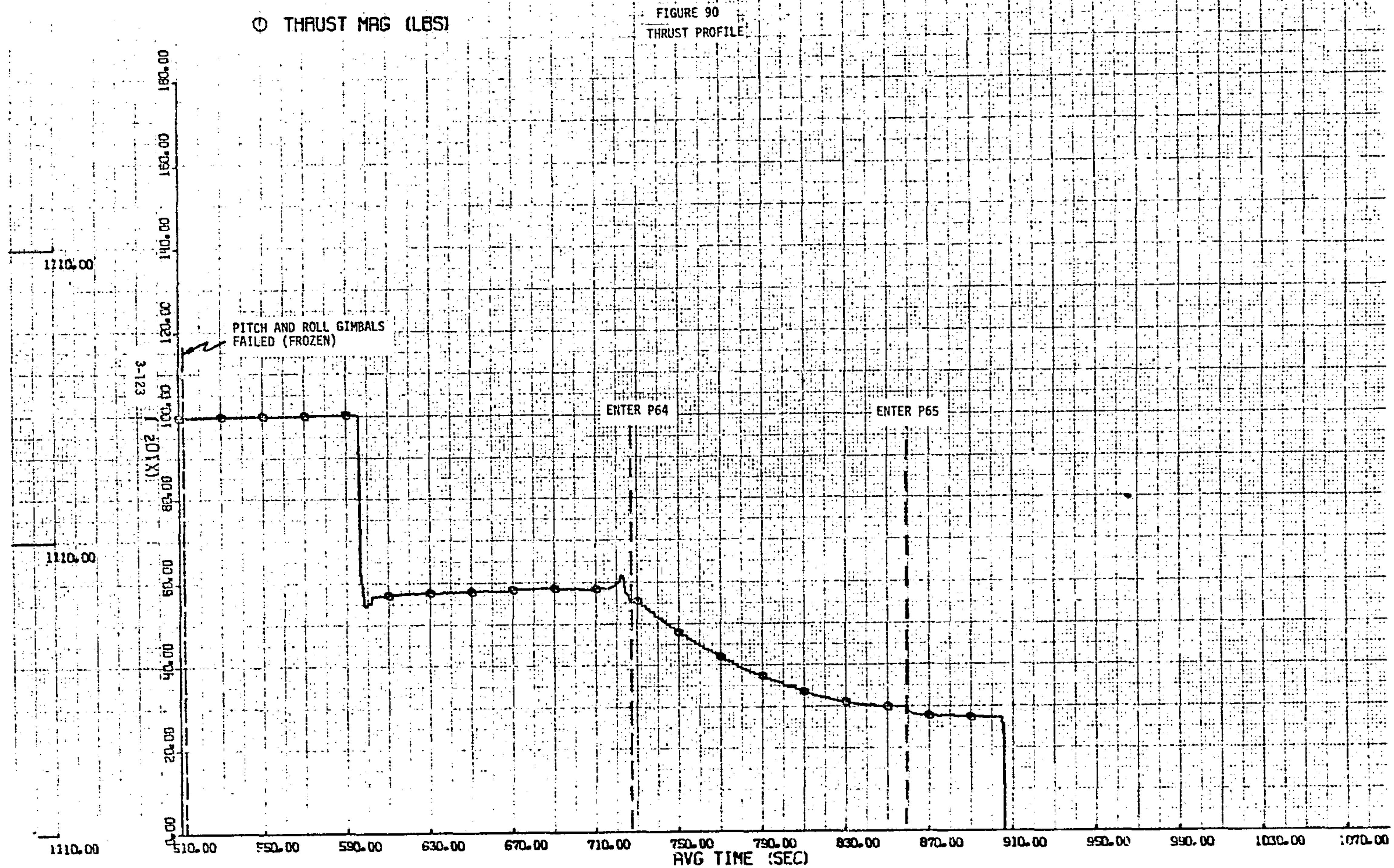


FIGURE 89
DPS ROLL GIMBAL ANGLE

LUNAR LANDING RUN H1-1.6.A

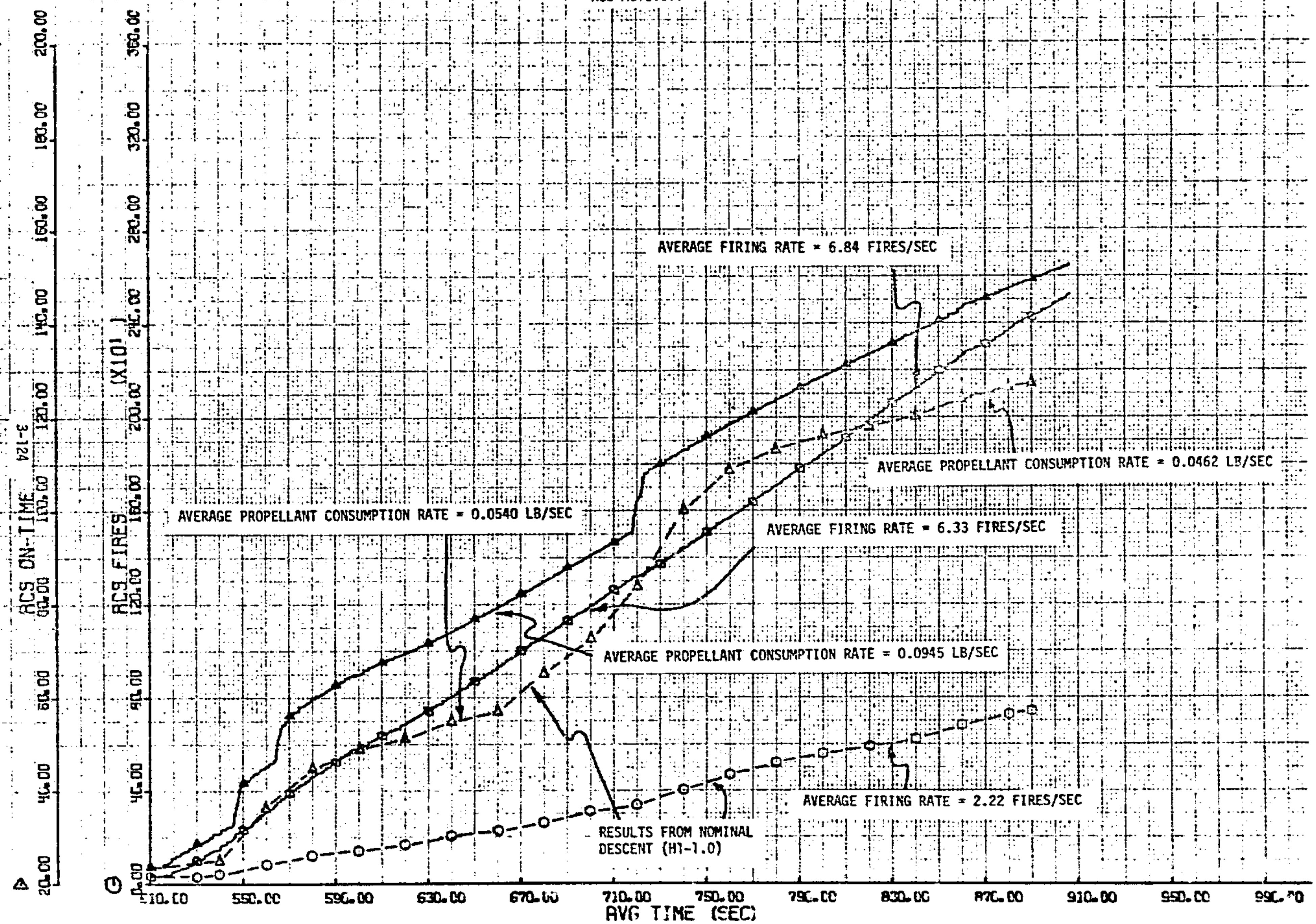
FIGURE 90
THRUST PROFILE



LUNAR LANDING RUN H1-1.6 A

FIGURE 91

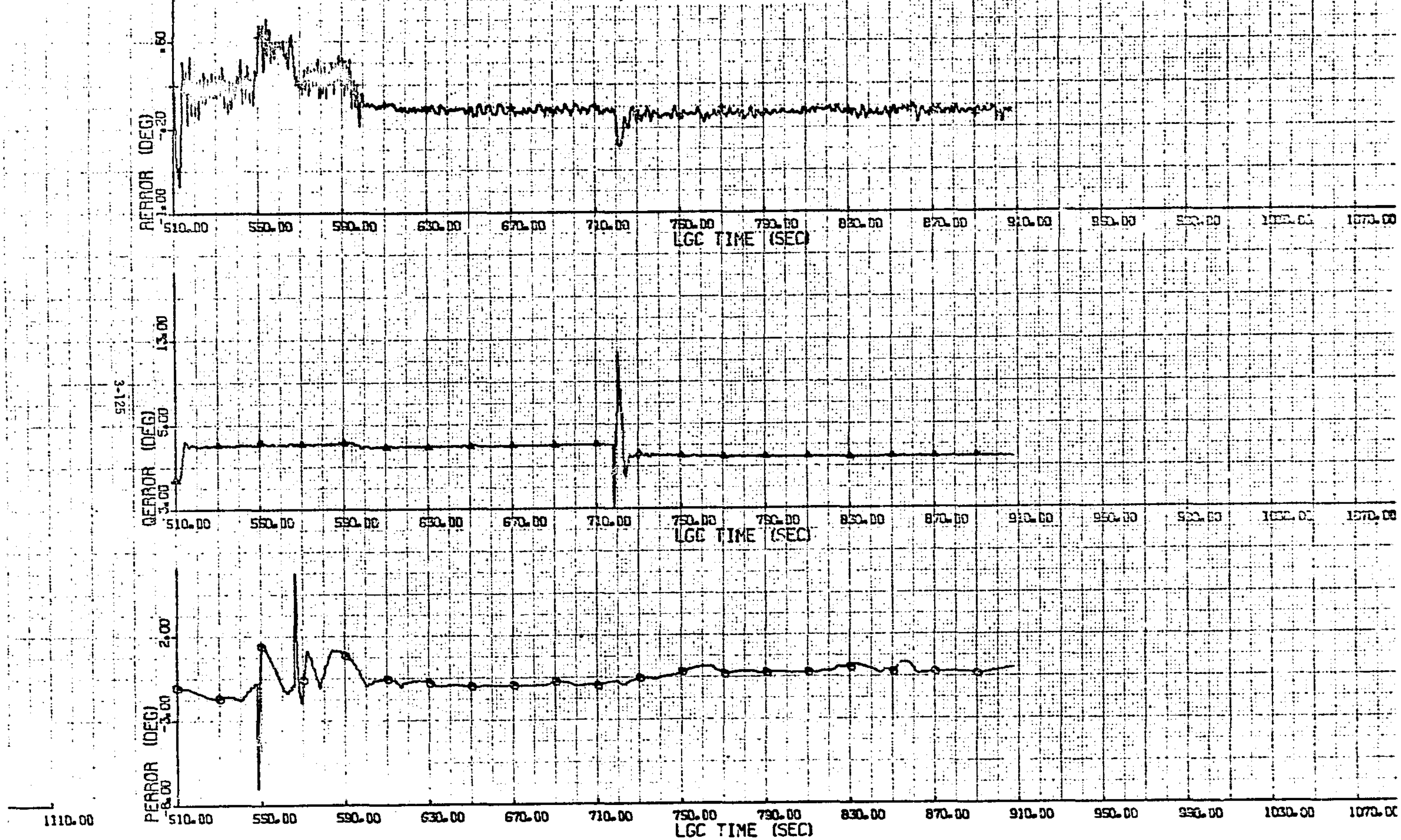
RCS ACTIVITY



LUNAR LANDING RUN H1-1.6 B

FIGURE 92

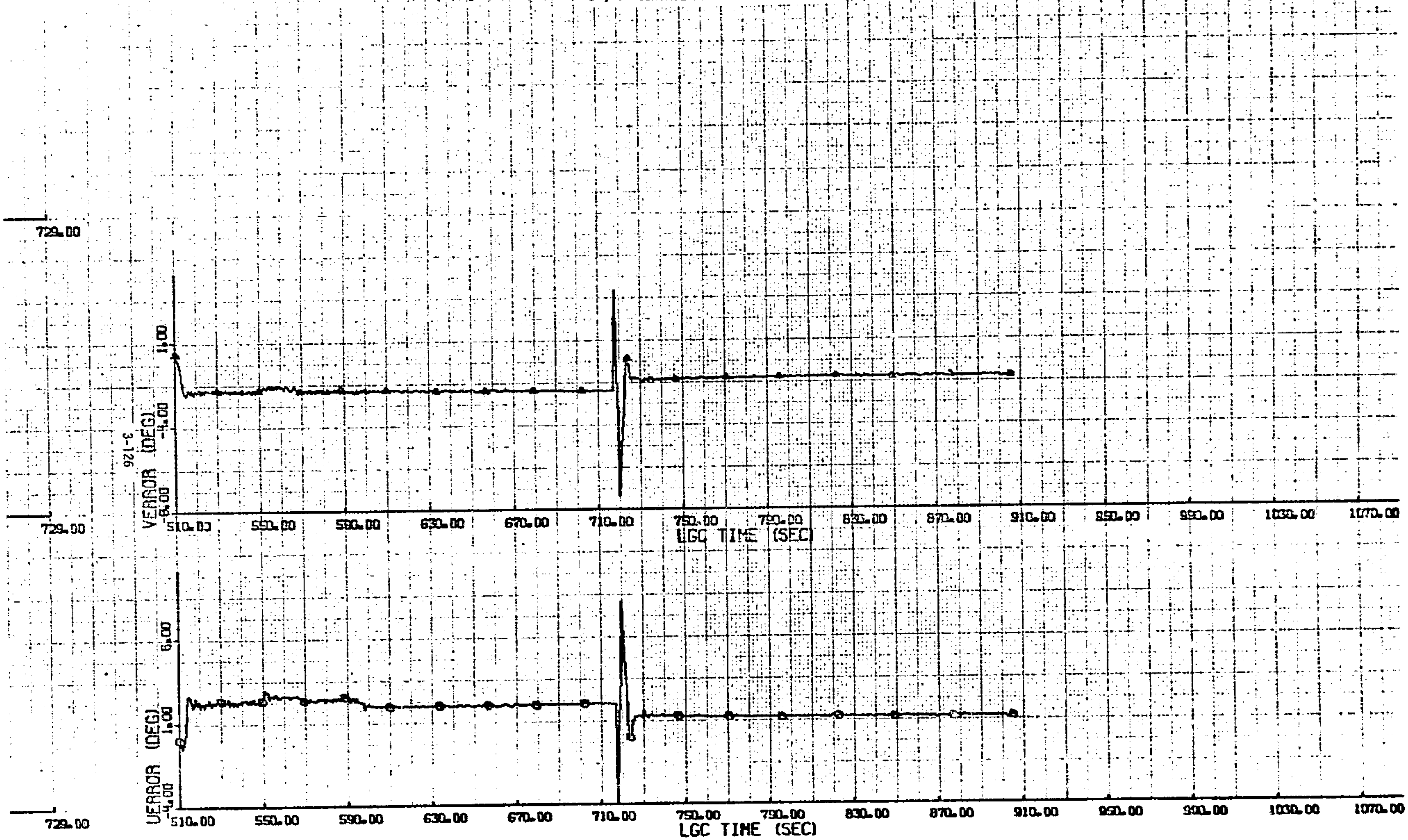
PITCH, YAW, AND ROLL ATTITUDE ERRORS



LUNAR LANDING RUN H1-1.6 B

FIGURE 93

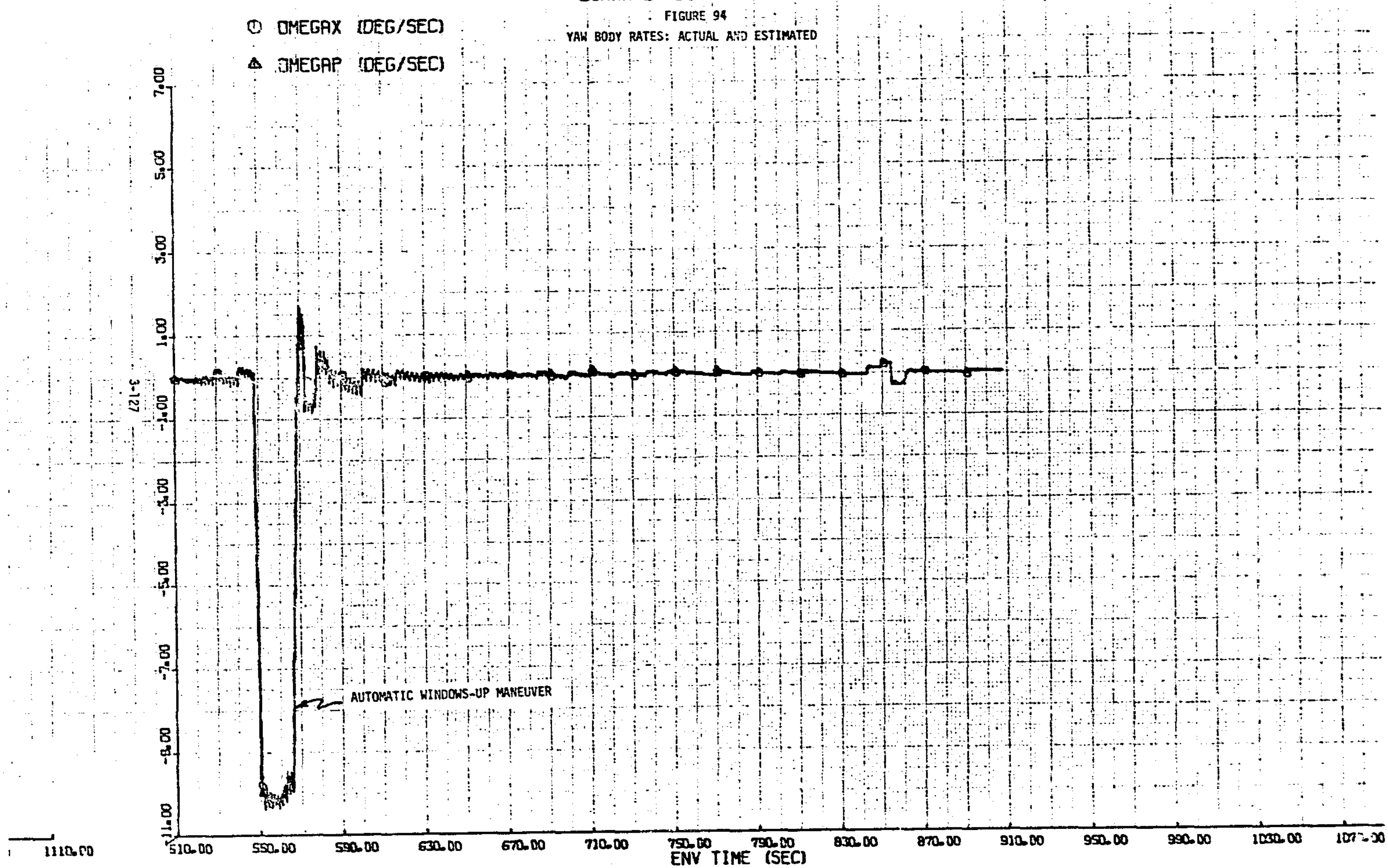
U', V' CONTROL AXES ATTITUDE ERRORS



LUNAR LANDING RUN H1-1.6 B

FIGURE 94

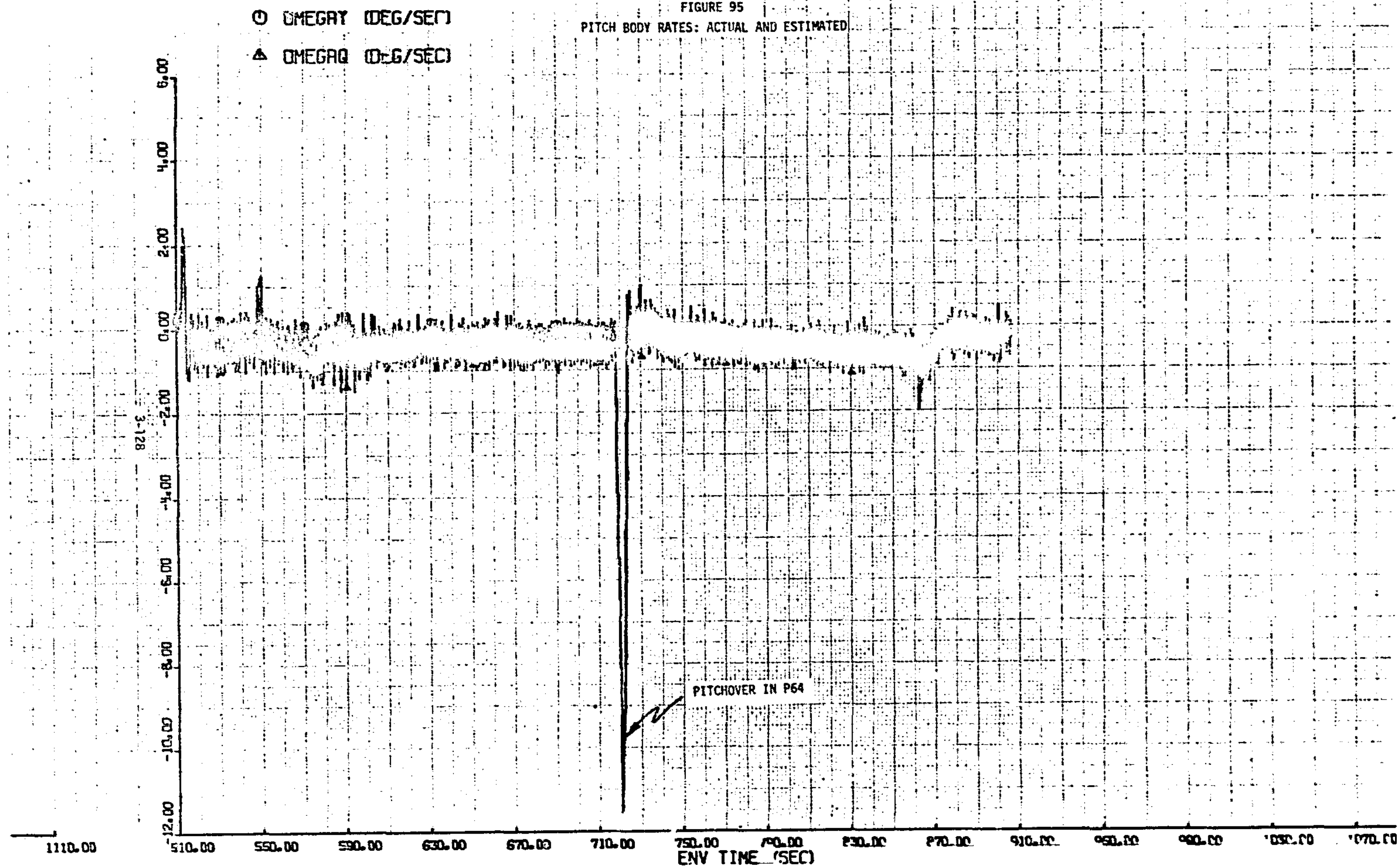
YAW BODY RATES: ACTUAL AND ESTIMATED



LUNAR LANDING RUN H1-1.6 B

FIGURE 95

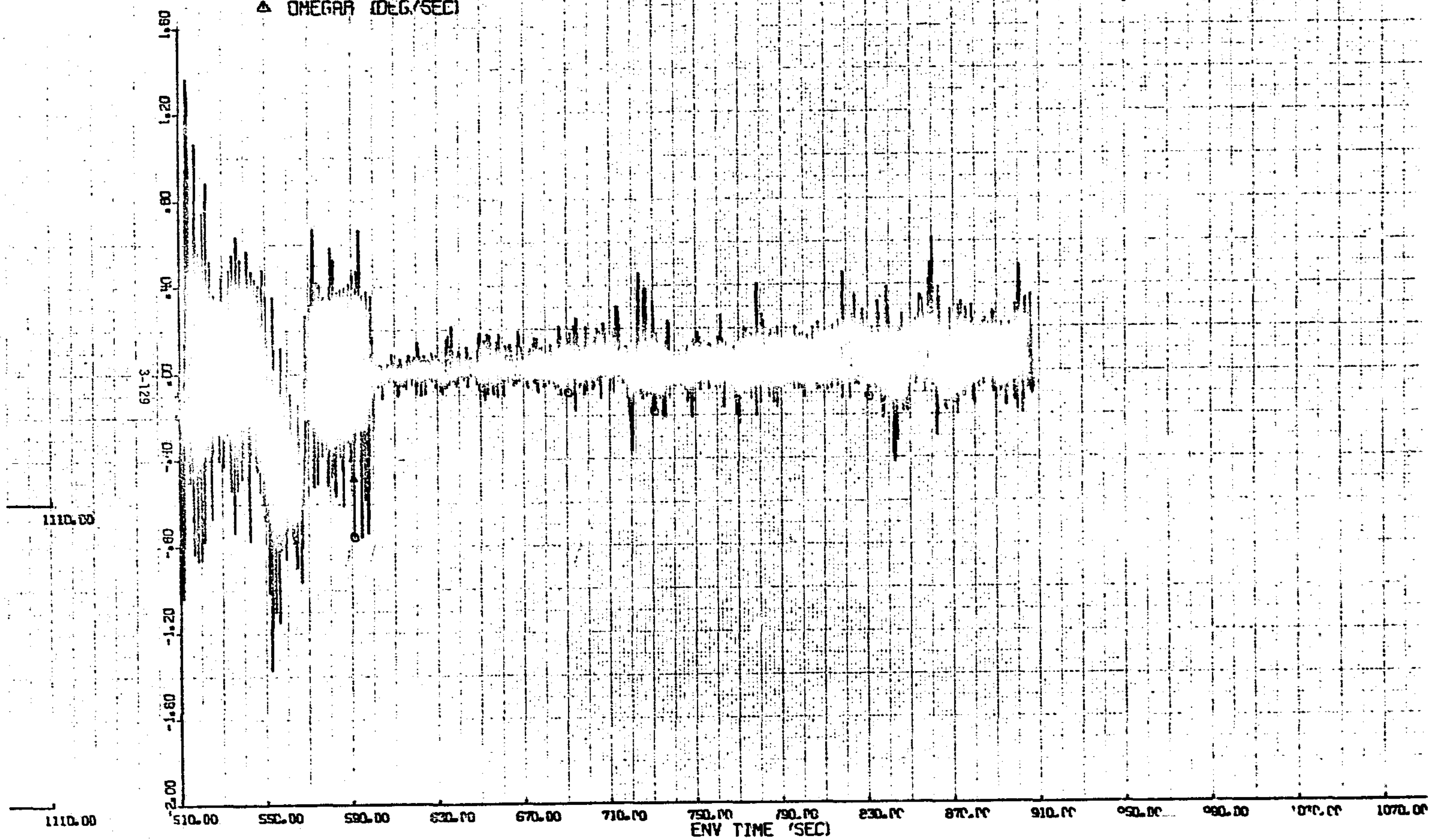
PITCH BODY RATES: ACTUAL AND ESTIMATED



LUNAR LANDING RUN H1-1.6 B

FIGURE 96

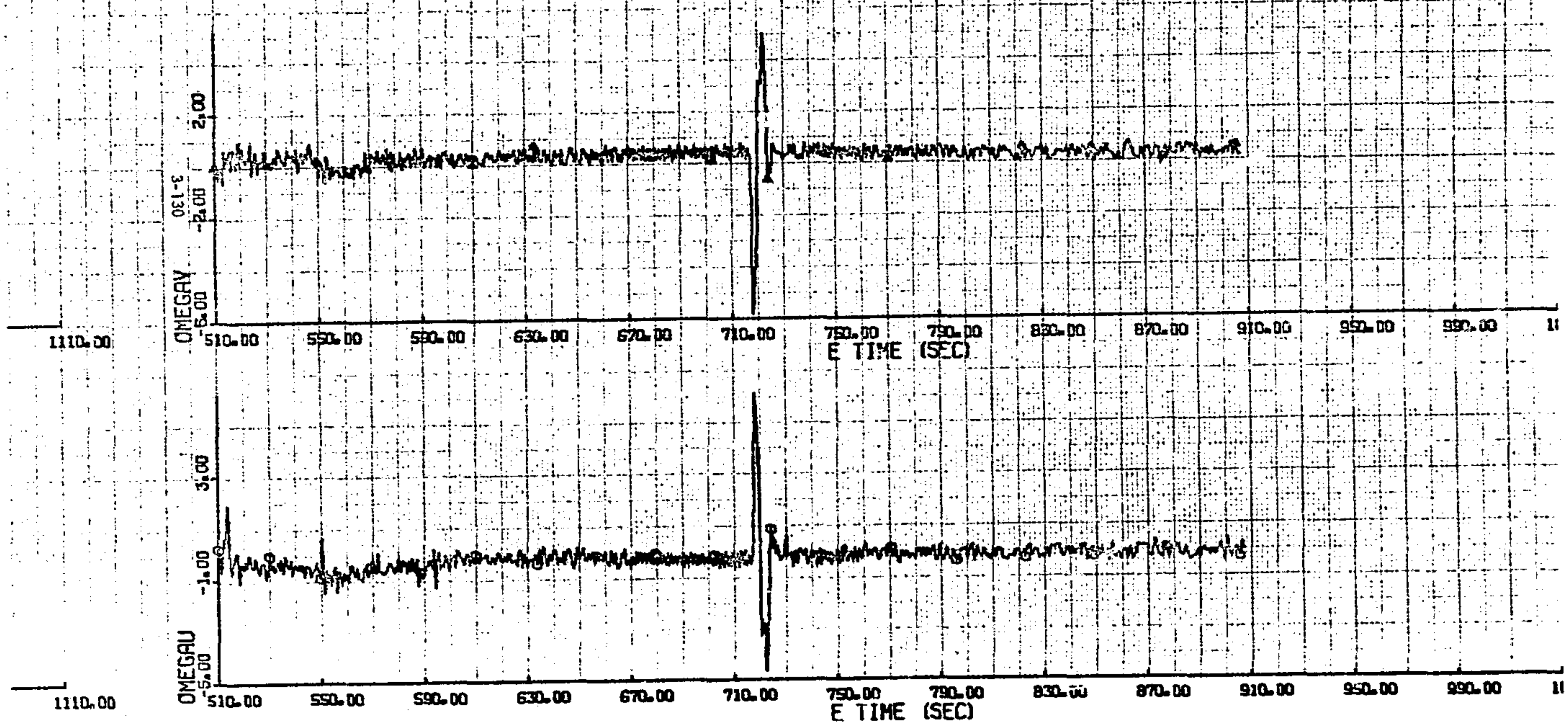
ROLL BODY RATES: ACTUAL AND ESTIMATED



LUNAR LANDING RUN H1-1.6 B

FIGURE 97

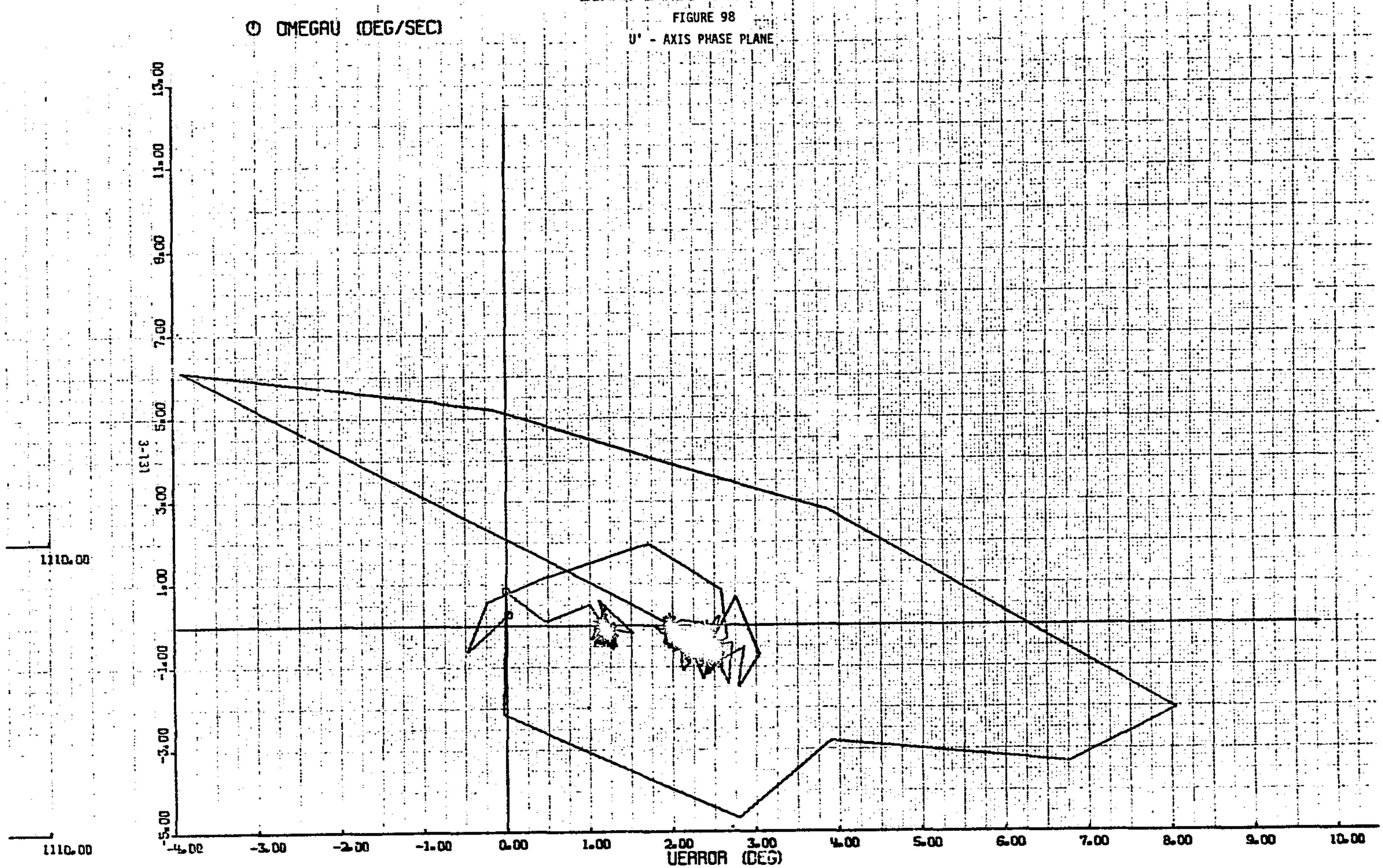
RATE ERRORS: U', V' - AXES



LUNAR LANDING RUN H1-1.6 B

FIGURE 98

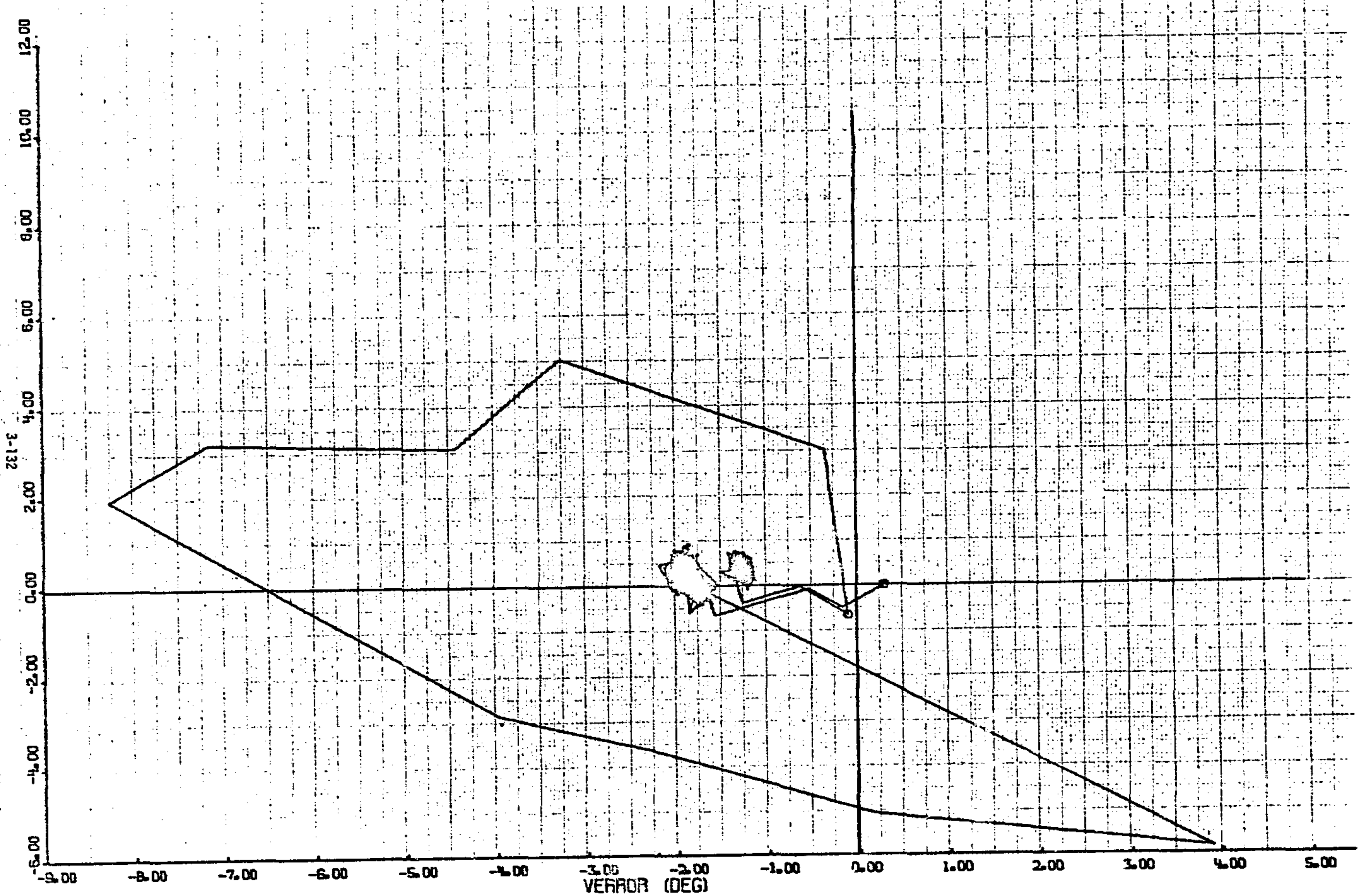
U' - AXIS PHASE PLANE



LUNAR LANDING RUN H1-1.6 B

FIGURE 99

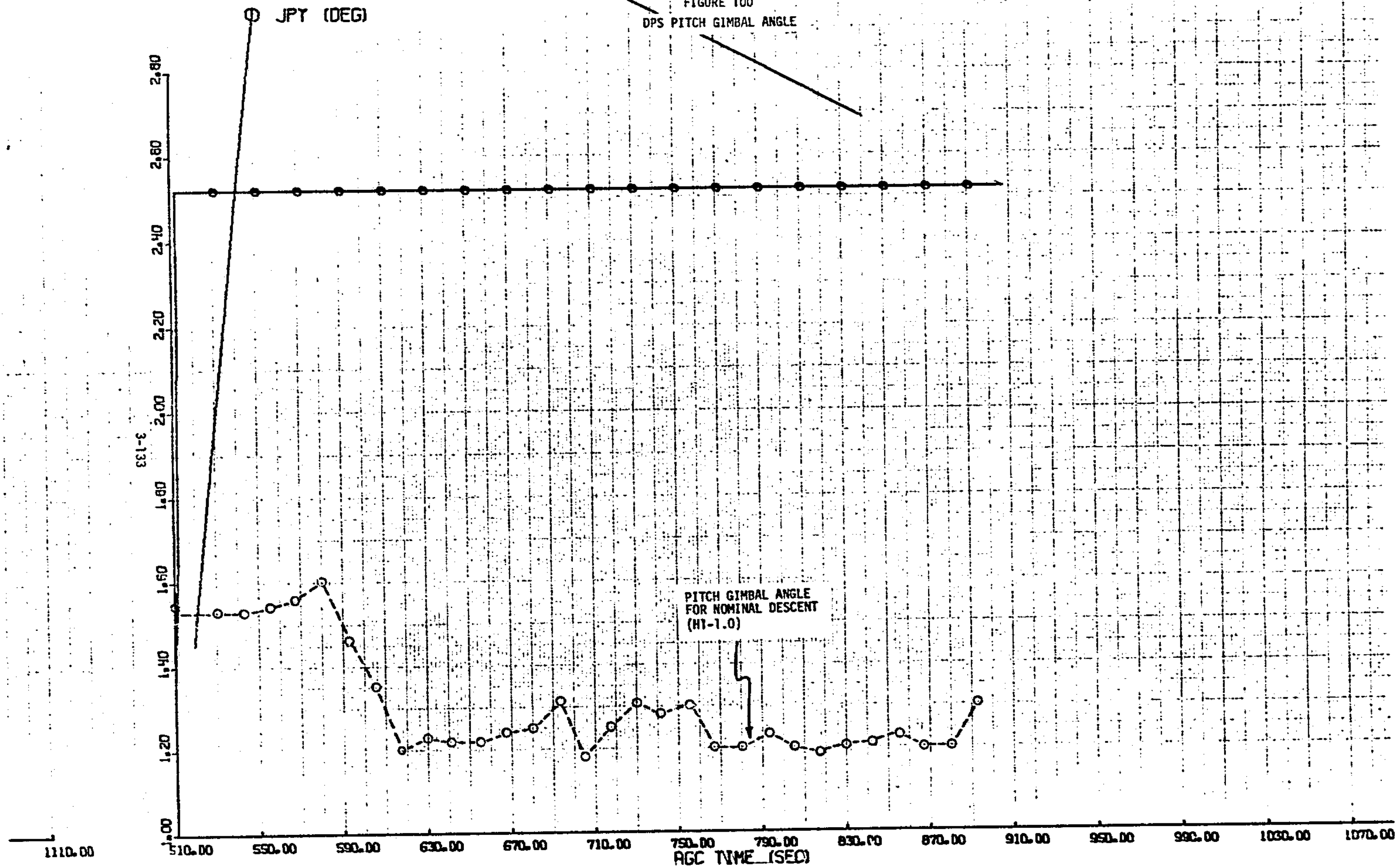
V' - AXIS PHASE PLANE



LUNAR LANDING RUN H1-1.6 B

FIGURE 100

DPS PITCH GIMBAL ANGLE



LUNAR LANDING RUN H1-1.6 B

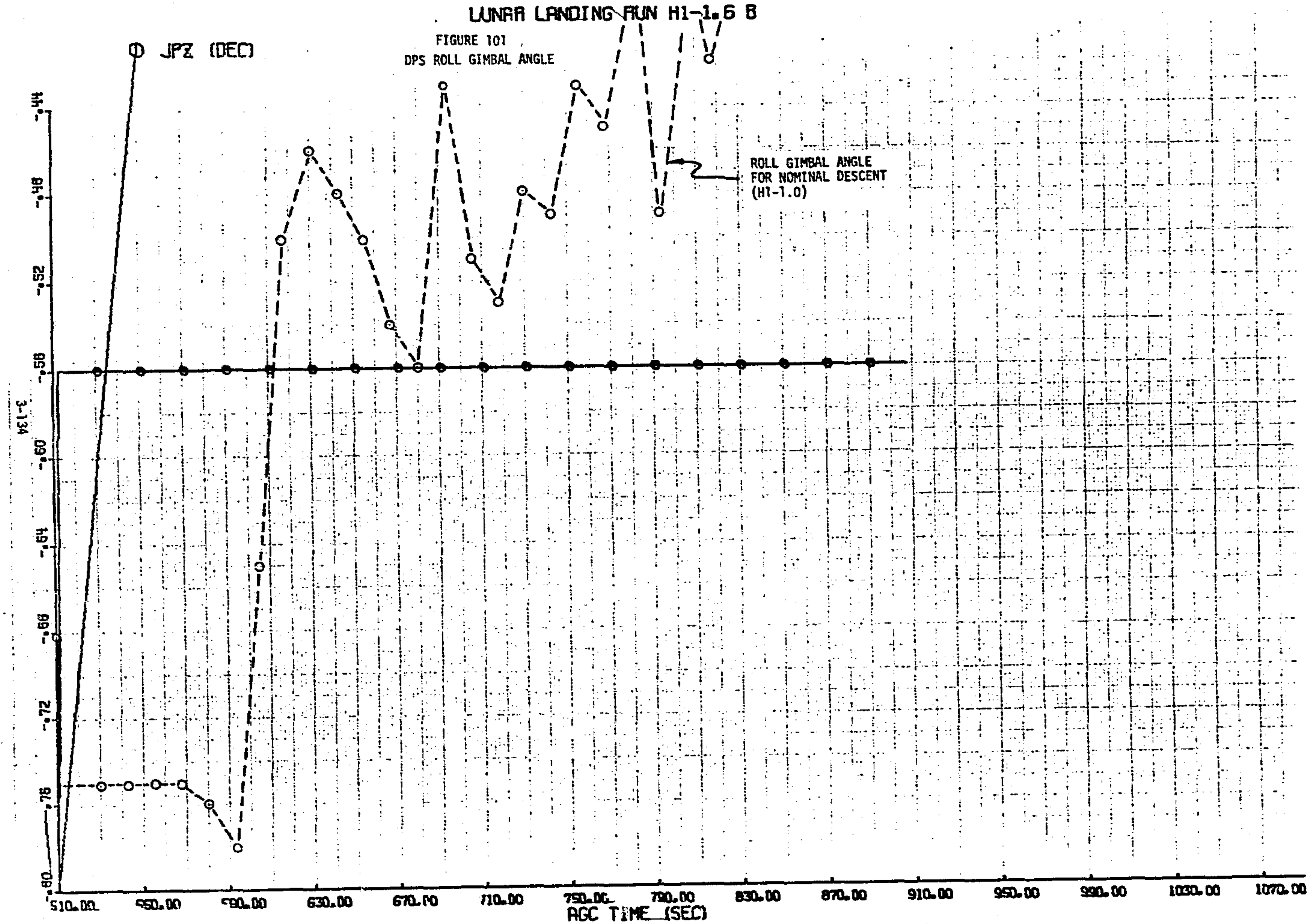
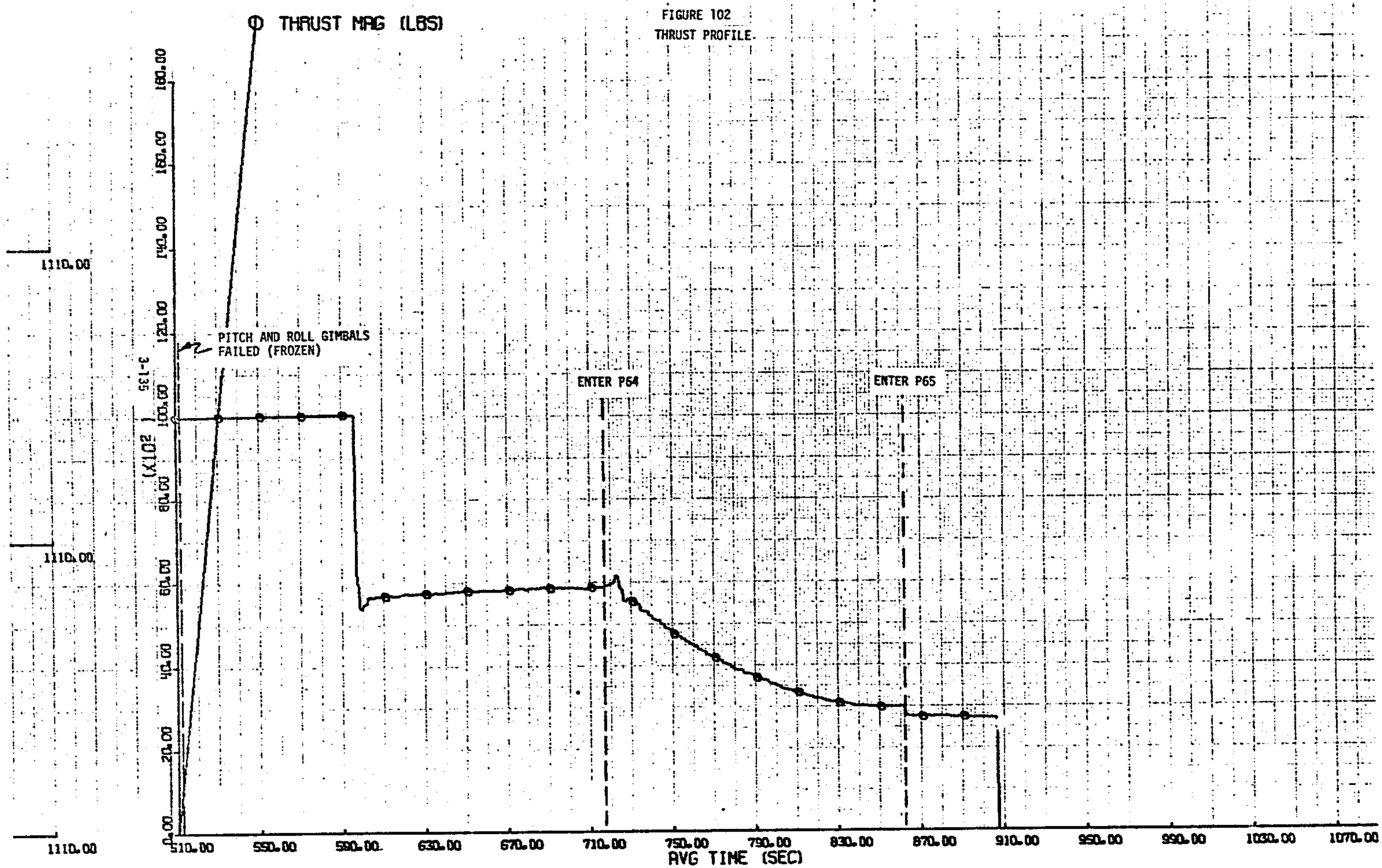


FIGURE 101
DPS ROLL GIMBAL ANGLE

LUNAR LANDING RUN H1-1.6 B

FIGURE 102

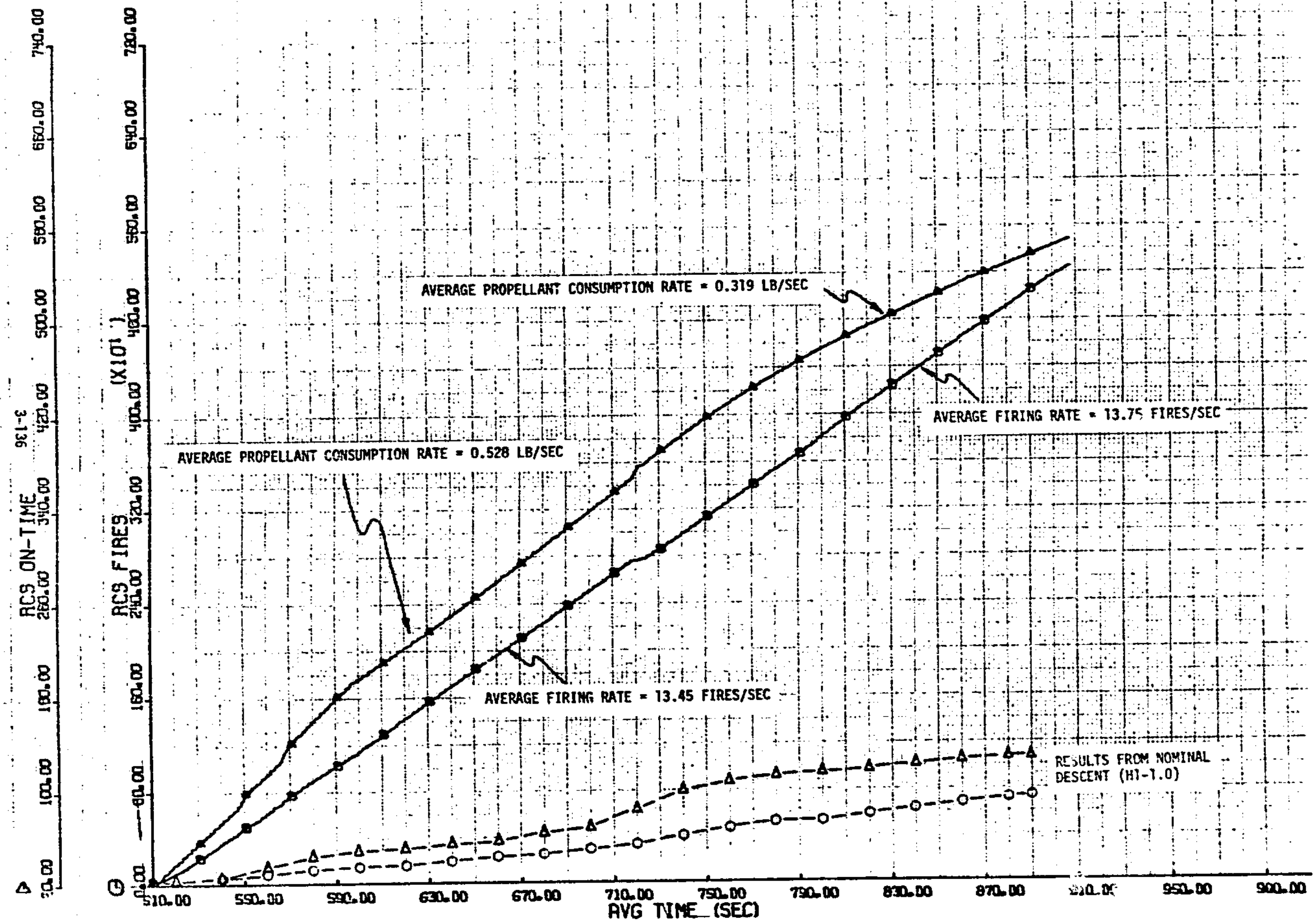
THRUST PROFILE



LUNAR LANDING RUN H1-1.6 B

FIGURE 103

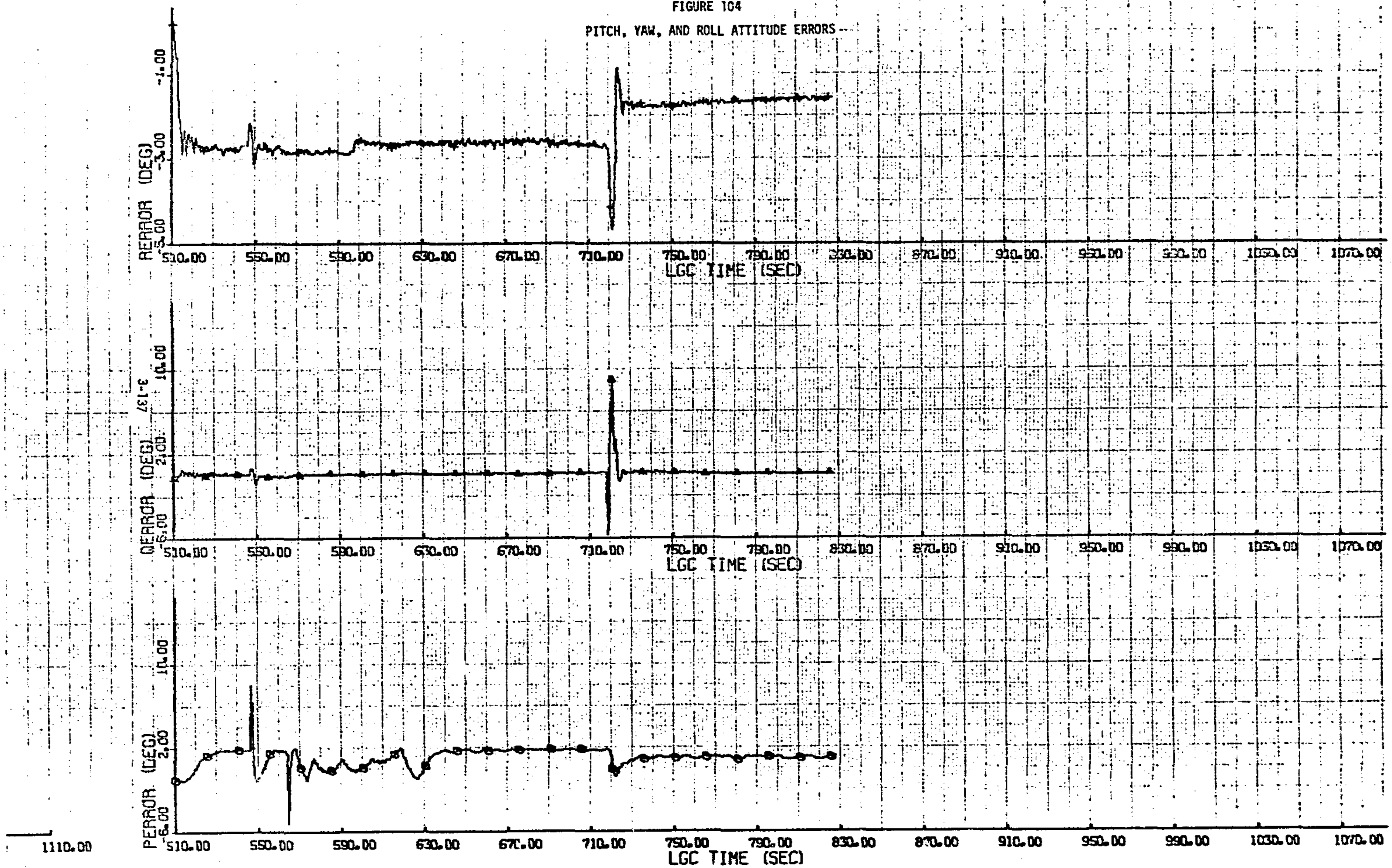
RCS ACTIVITY



LUNAR LANDING RUN H1-1.6 D

FIGURE 104

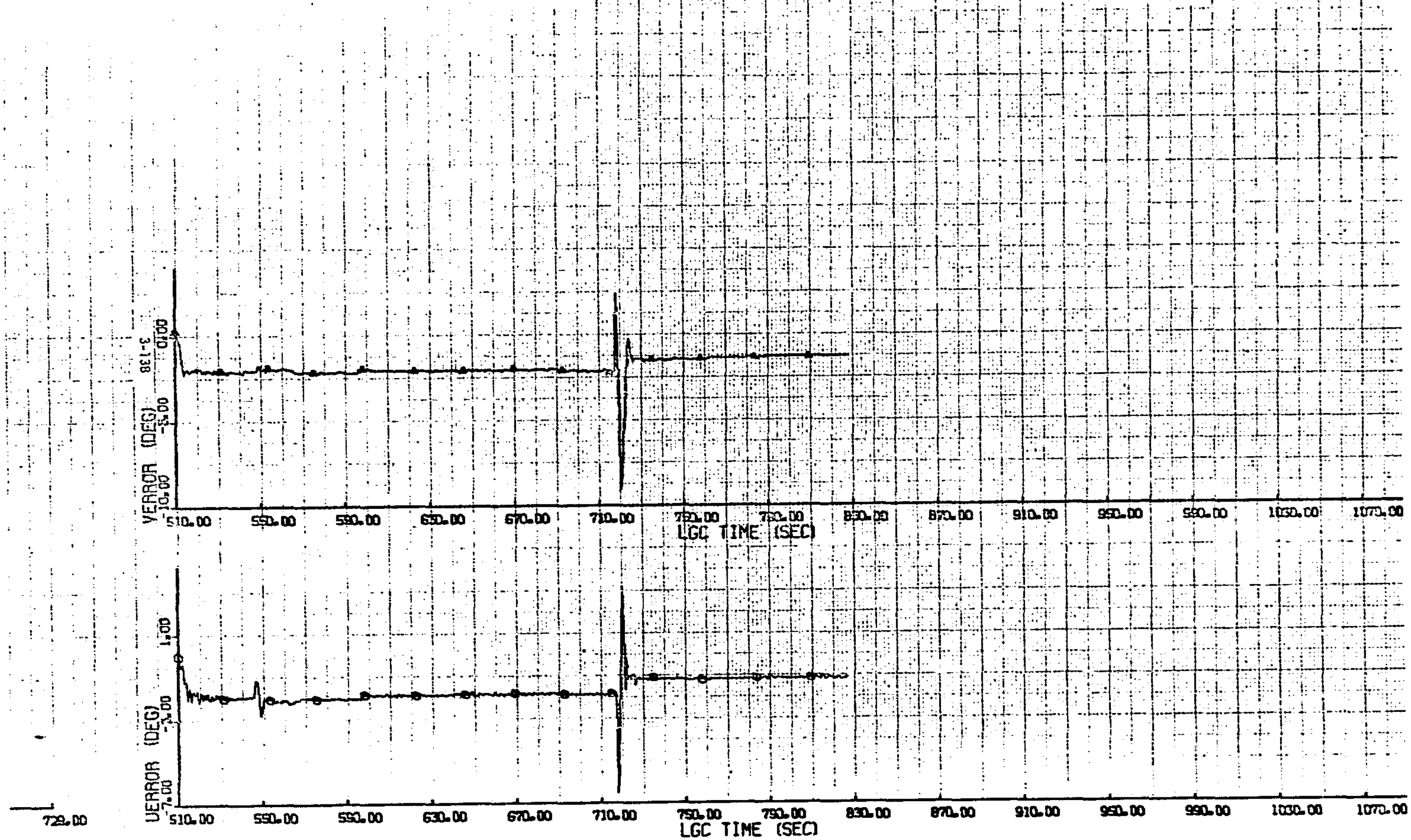
PITCH, YAW, AND ROLL ATTITUDE ERRORS



LUNAR LANDING RUN H1-1.6 D

FIGURE 105

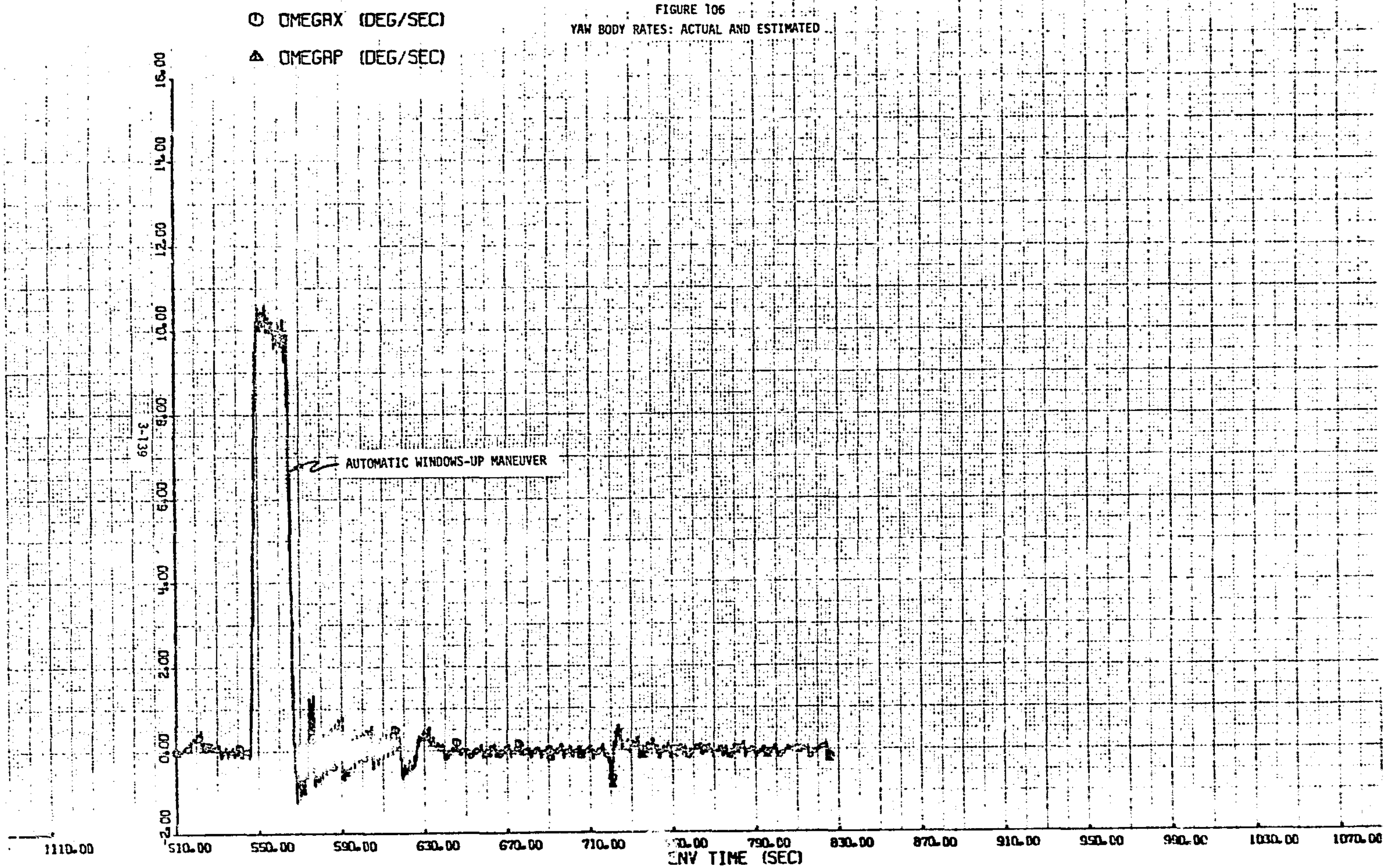
U', V' CONTROL AXES ATTITUDE ERRORS



LUNAR LANDING RUN H1-1.6 D

FIGURE 106

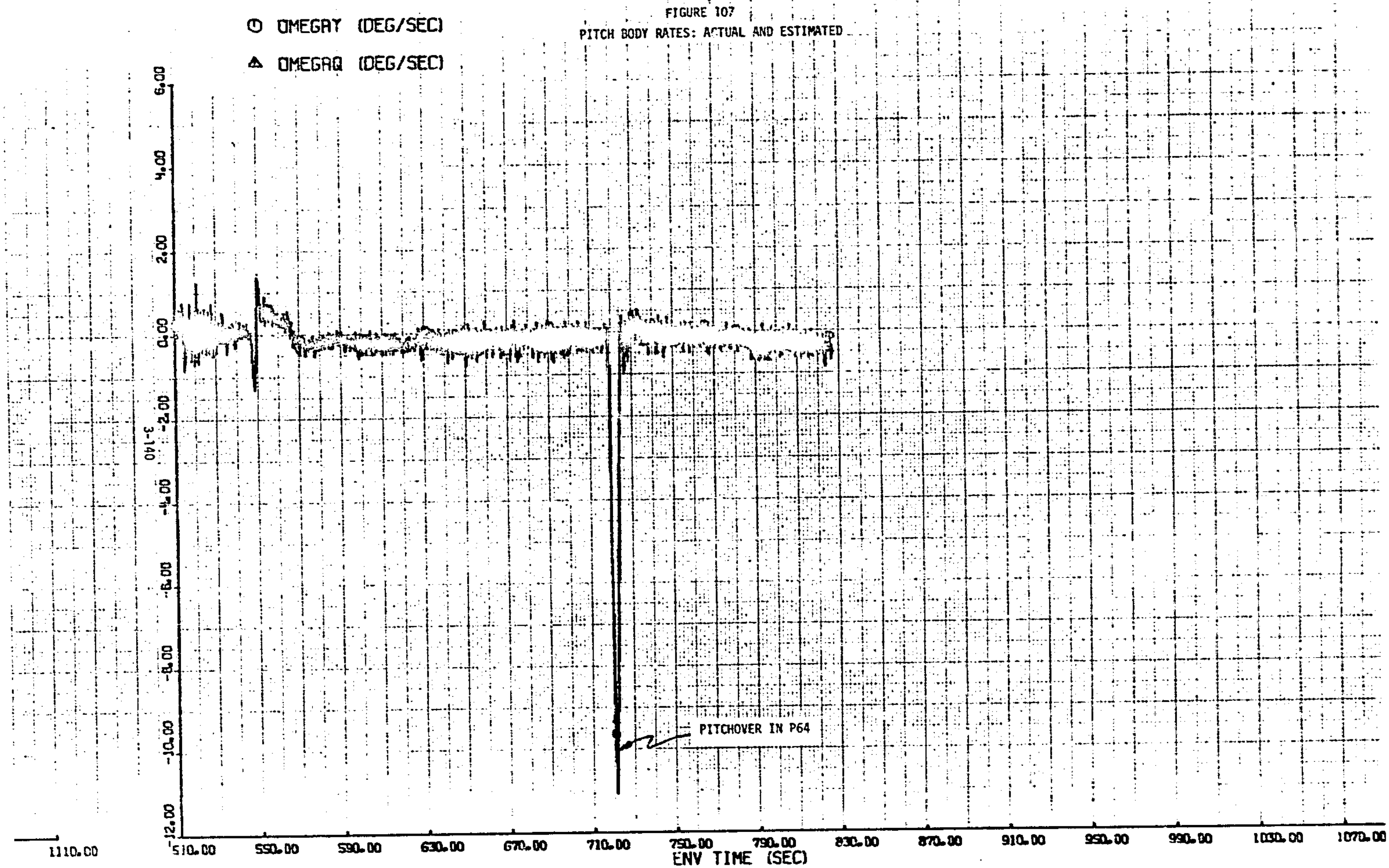
YAW BODY RATES: ACTUAL AND ESTIMATED

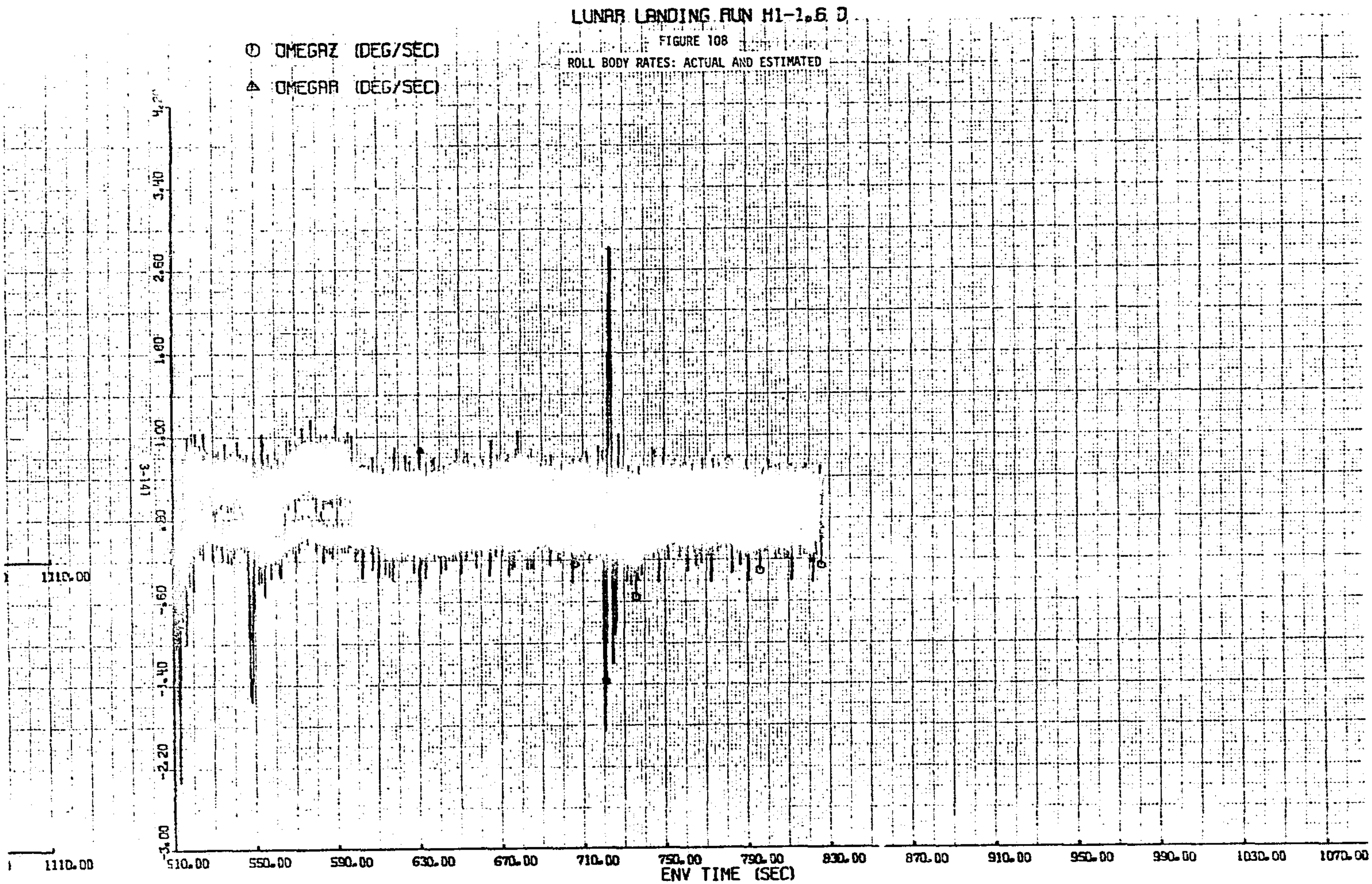


LUNAR LANDING RUN H1-1.6 D

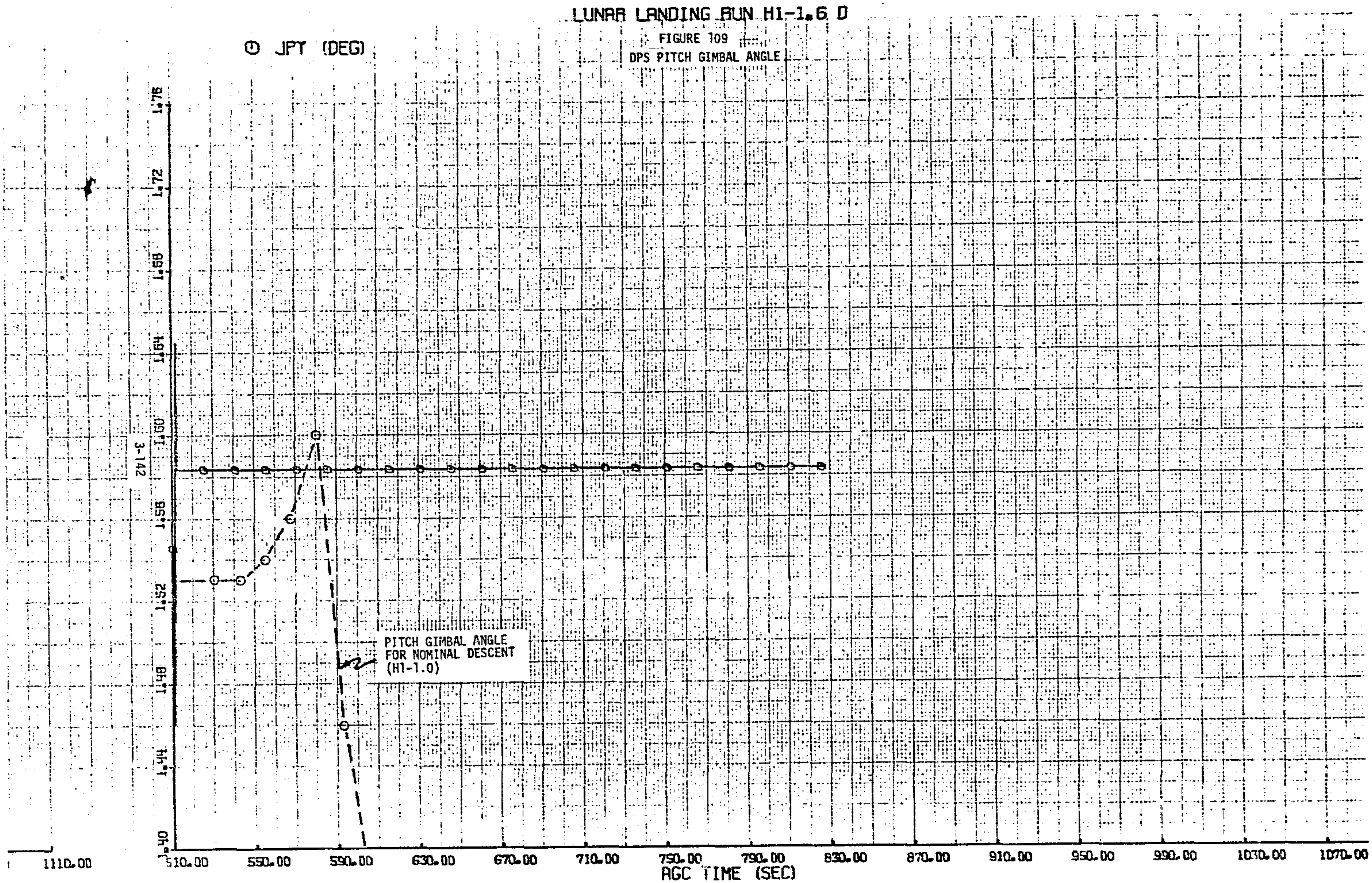
FIGURE 107

PITCH BODY RATES: ACTUAL AND ESTIMATED





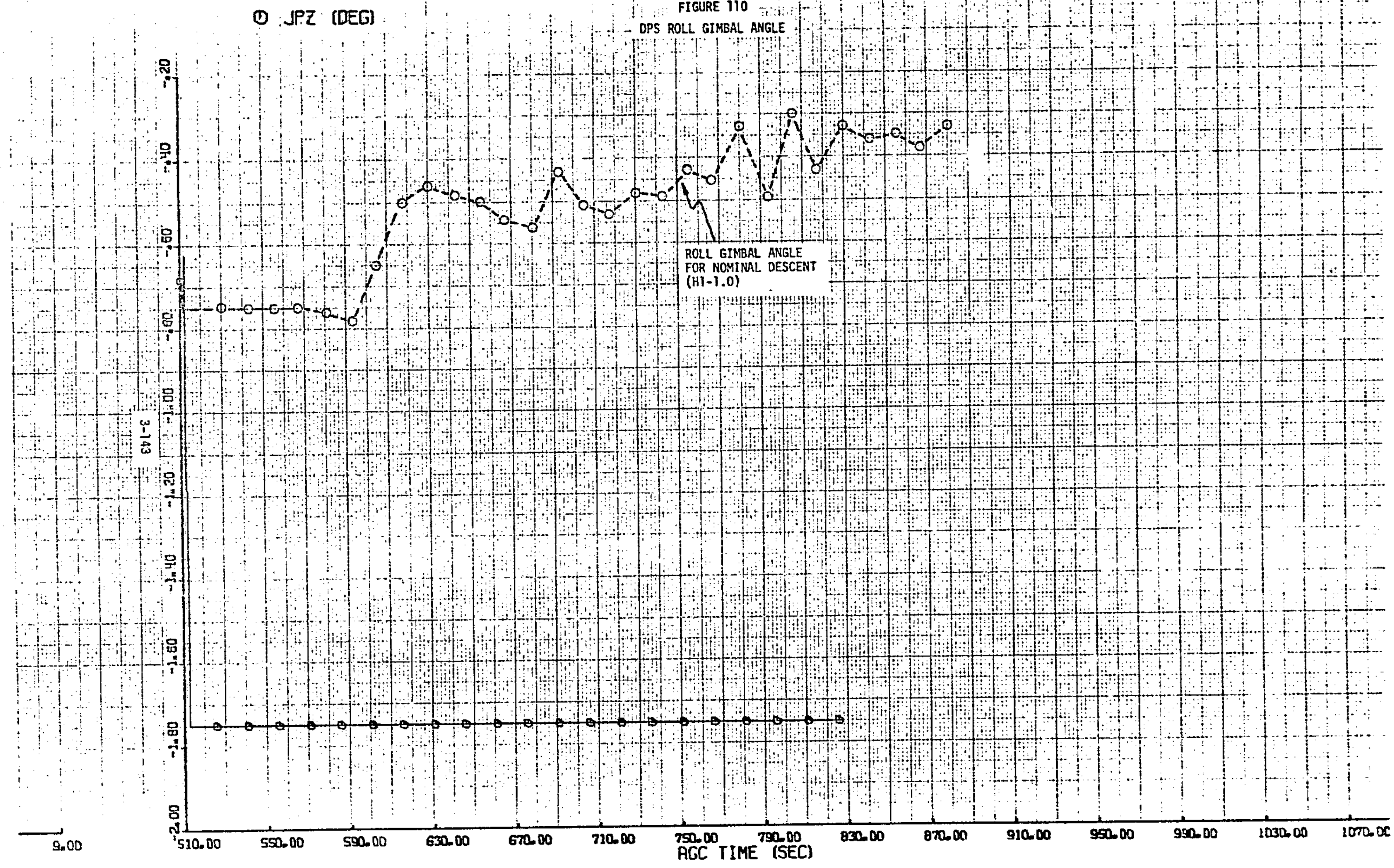
LUNAR LANDING RUN H1-1.6 D
FIGURE 108
ROLL BODY RATES: ACTUAL AND ESTIMATED
⊙ OMEGAZ (DEG/SEC)
△ OMEGAR (DEG/SEC)
3.40
2.60
1.80
1.00
.80
-.60
-1.40
-2.20
-3.00
510.00
550.00
590.00
630.00
670.00
710.00
750.00
790.00
830.00
870.00
910.00
950.00
990.00
1030.00
1070.00
1110.00
ENV TIME (SEC)


LUNAR LANDING RUN H1-1.6 D
FIGURE 109
DPS PITCH GIMBAL ANGLE
ʘ JPT (DEG)
PITCH GIMBAL ANGLE
FOR NOMINAL DESCENT
(H1-1.0)
1.40
1.44
1.48
1.52
1.56
1.60
1.64
1.68
1.72
1.76
510.00
550.00
590.00
630.00
670.00
710.00
750.00
790.00
830.00
870.00
910.00
950.00
990.00
1030.00
1070.00
1110.00
AGC TIME (SEC)

LUNAR LANDING RUN H1-1.6 D

FIGURE 110

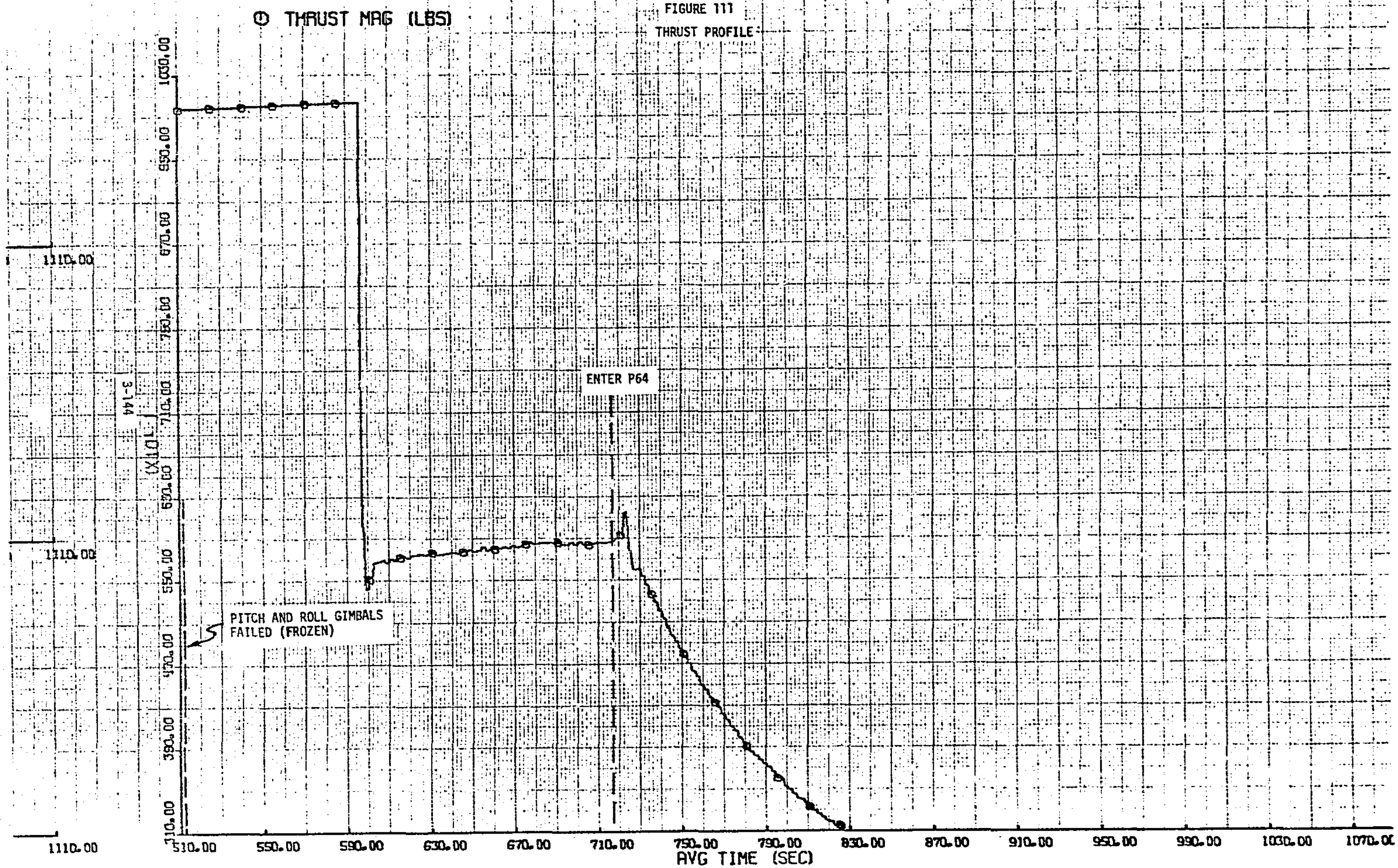
DPS ROLL GIMBAL ANGLE



LUNAR LANDING RUN H1-1.6 D

FIGURE 111

THRUST PROFILE



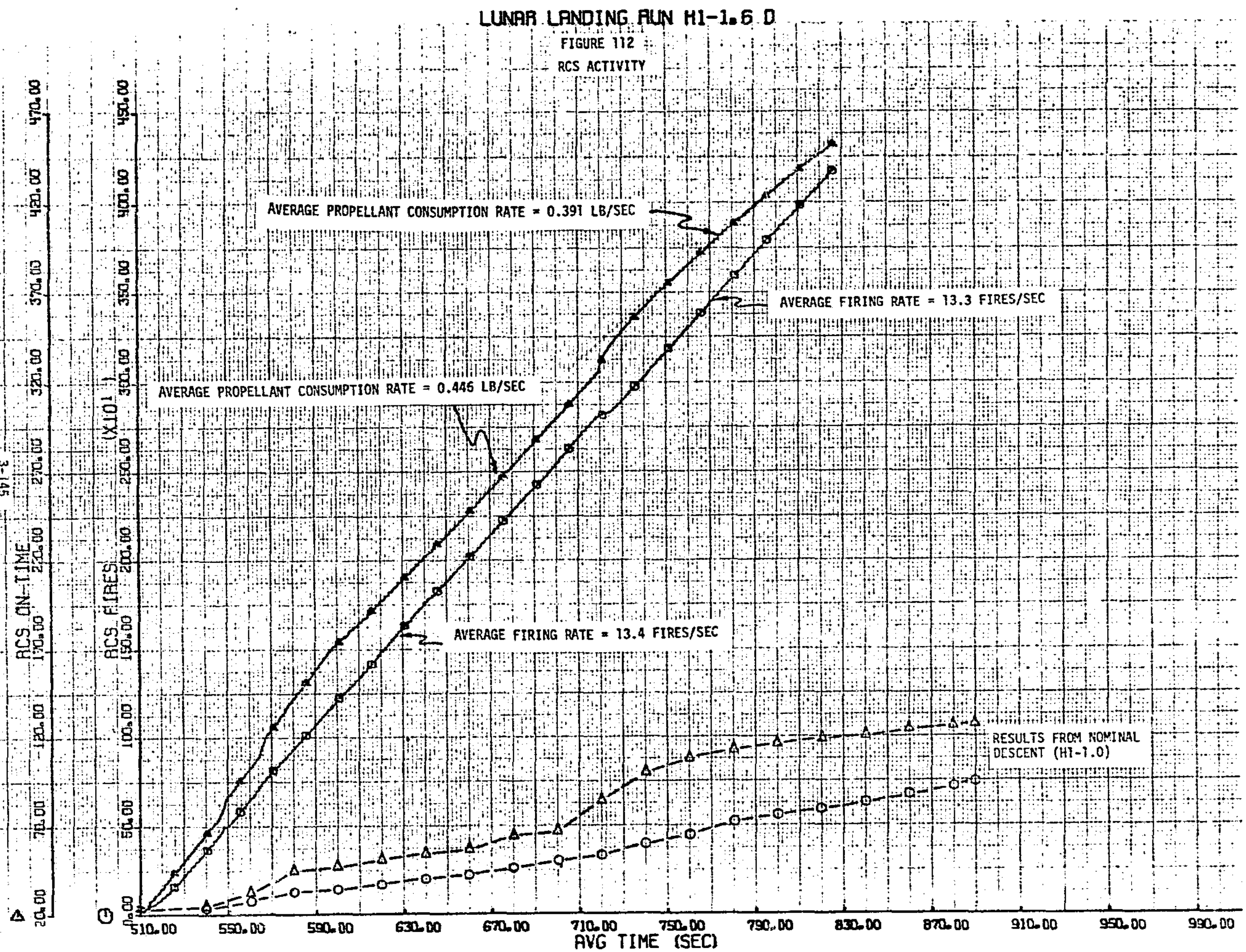

LUNAR LANDING RUN H1-1.6 D
FIGURE 112
RCS ACTIVITY
AVERAGE PROPELLANT CONSUMPTION RATE = 0.391 LB/SEC
AVERAGE FIRING RATE = 13.3 FIRES/SEC
AVERAGE PROPELLANT CONSUMPTION RATE = 0.446 LB/SEC
AVERAGE FIRING RATE = 13.4 FIRES/SEC
RESULTS FROM NOMINAL DESCENT (H1-1.0)
RCS ON-TIME
RCS FIRES (X10[1])
AVG TIME (SEC)
510.00 550.00 590.00 630.00 670.00 710.00 750.00 790.00 830.00 870.00 910.00 950.00 990.00
0.00 50.00 100.00 150.00 200.00 250.00 300.00 350.00 400.00 450.00
20.00 70.00 120.00 170.00 220.00 270.00 320.00 370.00 420.00 470.00

TABLE 5
KEY VARIABLES

Description	Run Number			
	Variable	H1 - 1.6A*	H1 - 1.6B*	H1 - 1.6D**
Maximum Attitude Errors (deg) (Time of Occurrence - sec)	PERROR	-7.75 (546)	-7.0 (548)	8.0 (547)
	QERROR	7.0 (720)	11.8 (720)	9.2 (721)
	RERROR	2.5 (537)	-7.5 (513)	-4.7 (722)
	UERROR	5.9 (719)	8.0 (720)	-6.6 (718)
	VERROR.	-5.7 (719)	-8.5 (720)	-8.5 (720)
Maximum Rates (deg/sec) (Time of Occurrence - sec)	OMEGAP	-10.5 (550)	-10.3 (552)	10.4 (551)
	OMEGAQ	-11.5 (721)	-11.5 (720)	-11.1 (721)
	OMEGAR	1.85 (548)	-1.4 (552)	2.82 (723)
	OMEGAU	5.9 (718)	6.2 (718)	6.8 (718)
	OMEGAV	-6.0 (718)	-5.8 (718)	-6.25 (718)
Average Peak-to-Peak Attitude Errors (deg)	QERROR	≈0.1	≈0.1	≈0.1
	RERROR	≈0.15	≈0.1	≈0.1
	UERROR	≈0.15	≈0.1	≈0.1
	VERROR	≈0.1	≈0.1	≈0.1

*Entries in this column are for the time period of T = 510.0 sec to touchdown.

**Entries in this column are for the time period of T = 510.0 sec to T = 825.0 sec.

TABLE 5 (Continued)
KEY VARIABLES

Description	Run Number			
	Variable	H1 - 1.6A*	H1 - 1.6B*	H1 - 1.6D**
Average Peak-To-Peak Rates (deg/sec)	OMEGAQ	0.5	0.7	0.6
	OMEGAR	0.5	0.7	0.5
	OMEGAU	0.4	0.7	0.7
	OMEGAV	0.4	0.7	0.6

*Entries in this column are for the time period of T = 510.0 sec to touchdown.

**Entries in this column are for the time period of T = 510.0 sec to T = 825.0 sec.

TABLE 6
RCS ACTIVITY SUMMARY
(End of Ullage to Touchdown)

Jet No.	Run H1-1.6A		Run H1-1.6B		Run H1-1.6D*	
	Jet On Time (sec)	No. of Fires	Jet On Time (sec)	No. of Fires	Jet On Time (sec)	No. of Fires
1	26.903	577	131.963	1345	121.471	1070
2	7.786	130	0.896	5	0.911	5
3	3.083	17	2.896	6	5.008	62
4	1.222	15	1.332	29	2.326	5
5	1.471	7	0.532	1	80.009	869
6	20.509	485	131.555	1199	1.200	2
7	3.081	16	3.189	30	1.334	9
8	1.182	15	0.789	5	2.497	60
9	7.772	129	0.907	6	0.923	6
10	26.842	572	132.010	1349	121.458	1069
11	3.083	17	2.896	6	5.008	62
12	1.222	15	1.332	29	2.326	5
13	20.478	482	131.542	1198	1.200	2
14	1.471	7	0.532	1	80.021	870
15	3.081	16	3.189	30	1.334	9
16	1.182	15	0.789	5	2.497	60
Total On Time of All Jets (sec)	130.368		546.349		429.523	
Total No. of Fires	2515		5244		4165	
Total Propellant (lbs)	53.1281		211.5506		166.4022	

* Run H1-1.6D did not go all the way to touchdown but was terminated at T = 825.2204 sec.

4.0 CONCLUSIONS

From the analyses and results of the ten simulations made, it was found that DAP operation and guidance interfacing in programs P63, P64, P65, P70, and P71 were nominal. Fuel slosh effects continue to be present in the descent sequence but are reduced in amplitude in P64 and P65 due to the new 0.3 degree deadband. The predicted fuel sloshing is not considered a serious problem. Successful completion of lunar descent under conditions with frozen DPS gimbals were obtained. Run H1-1.6D did not land due to a problem in the simulator. However, the results prior to the landing difficulty were valid. RCS consumption was found to be very sensitive to initial thrust misalignments at the time of failure. Proper deadband sequencing was verified for late use of abort programs P70 and P71.

5. REFERENCES

1. MIT/IL R-567, GSOP (LUM 1B, Rev 116) Section 3, dated August 1969

2. TRW Project Technical Report NAS 9-8166, 11176-H287-RO-00, "Digital Autopilot Software Verification Test Results for the Apollo 11 Mission - Luminary 1A", dated 14 July 1969.

3. TRW IOC 69:7254.4-146, "Slosh Instability During Descent of Apollo 11", by T.J. Lee, dated 6 October 1969.

4. MIT/IL R-567, GSOP Section 6, dated November 1969.

5. TRW Project Technical Report NAS 9-8166, 11176-H365-RO-00, "Apollo 11 DAP Postflight Analysis", dated 17 October 1969.