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PROJECT TECHNICAL REPORT

TASK ASTP-E101

CSM DIGITAL AUTOPILOT TESTING IN SUPPORT OF ASTP EXPERIMENTS CONTROL REQUIREMENTS

NAS 9-13834

15 JANUARY 1975

Prepared for
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
JOHNSON SPACE CENTER
HOUSTON, TEXAS

Prepared by
Operations and Evaluations Section
Subsystems Engineering and Analysis Department

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CONTENTS

1. INTRODUCTION AND SUMMARY

This report presents the results of CSM digital autopilot (DAP) testing. The testing was performed to demonstrate and evaluate control modes which are currently planned or could be considered for use in support of experiments on the ASTP mission. The testing was performed on the Lockheed Guidance, Navigation, and Control System Functional Simulator (GNCFS). This simulator, which was designed to test the Apollo and Skylab DAP control system, has been used extensively and is a proven tool for CSM DAP analysis.

The control modes selected for simulation were those control modes which have special characteristics or requirements, e.g., certain RCS thrusters disabled, and have not been thoroughly evaluated in previous ASTP simulation testing. References 1 and 2 present results of DAP studies for the CSM/DM configuration and CSM/DM/Soyuz configuration, respectively, and report primarily on standard control modes such as attitude hold, automatic and manual attitude maneuvers, and RCS translations. This study reports on control modes which are of an off-nominal nature and are summarized below:

VEHICLE CONFIGURATION	CONTROL MODE	APPLICABLE EXPERIMENT	SIMULATION CASE
CSM/DM	Attitude hold with convergence to minimum attainable body rates followed by a period of free drift.	MA007	1
CSM/DM/Soyuz	Attitude maneuver followed by attitude hold in the Docked DAP force mode with single jet roll control. RCS thrusters inhibited internal to the DAP.	MA010	2
CSM/DM/Soyuz	Attitude maneuver followed by attitude hold in the Docked DAP force mode with single jet roll control. RCS thrusters inhibited external to the DAP.	MA010	3
CSM/DM/Soyuz	Attitude maneuver followed by attitude hold in the Docked DAP coupled mode with forward firing thrusters inhibited and with single jet roll control. RCS thrusters inhibited external to the DAP.	MA010	3A

VEHICLE CONFIGURATION	CONTROL MODE	APPLICABLE EXPERIMENT	SIMULATION CASE
CSM/DM	Attitude maneuver to preferred attitude followed by vehicle spin-up (0.3°/sec) about the X axis and with jets A2, A4, B1, and B4 disabled.	MA048	4
CSM/DM	Attitude maneuver to preferred attitude followed by vehicle spin-up (0.5°/sec) about the X axis and with jets A3, B3, C4, and D4 disabled.	MA059	5
CSM	Attitude maneuver to each of three candidate preferred attitudes followed by orbit rate control about a specific axis simulating tracking of another orbiting body.	MA089	6, 6A, 6B
CSM/DM	Two RCS -X translations separated by an attitude hold coast period simulating the CSM/DM separation sequence from the Soyuz.	MA148	7

All of the testing included rigid body and gravity gradient effects. For the CSM/DM/Soyuz runs, the effects of aerodynamics were added.

Run results are presented in Section 2. Each run is described in terms of objective, test configuration and sequence, and conclusions based on data acquired. Evaluation criteria for each run were derived from several sources but primarily Reference 3, the ASTP Mission Requirements document. Evaluation criteria are summarized in the objective section of each run analysis. Of the ten control system cases studied, two problems are apparent in meeting experiment requirements and limitations. In Cases 2, 3, and 3A, the Docked DAP was set up in various configurations to provide angular accelerations within the MA010 experiment limitations ($2.75°/sec^2$ in roll and $0.57°/sec^2$ in P and Y). MA010, the crystal growth experiment, requires minimum acceleration effects during the crystal growing period which is 29 hours during the docked mission phase. With the docked vehicle, the P and Y limitation can be met with normal jet configuration control, but the roll limitation requires single jet roll control. The most efficient rotational control during docked operation is with forced pair mode, i.e., use the roll thruster firings in the same direction to effect P and Y rotations. If jets are inhibited however, to provide single jet roll control, the effectiveness of the force mode is reduced. The other available option, standard coupled mode P and Y control, is already limited during docked operation because forward firing thrusters are inhibited in order to meet Soyuz heating constraints. The final consequence of all these limitations is an inefficient control system regardless of the Docked DAP mode used. Since the experiment duration is so long, it's impractical to consider using a control mode that could consume as a minimum, 14 lbs of fuel per orbit. It is therefore highly unlikely that the operational requirements, i.e., maintenance of some attitude control, and the experiment requirements can be met simultaneously when in the docked configuration.

The second problem is associated with Case 7; the separation sequence simulating the CSM eclipsing of the sun during the experiment MA148 photography of the solar corona. The experiment requirement desires a viewing period of five minutes; however, from simulation data it's highly unlikely that the CSM occultation of the sun will last much longer than 2-1/2 minutes. Consideration might be given to biasing off the initial pointing attitude in an attempt to compensate for known disturbing torques (e.g., RCS thrusting c.g. offset) and allow the torques to drive the CSM toward the desired line-of-sight instead of away from the line-of-sight.

2. SIMULATION TEST RESULTS

This section presents the analysis and results for each test case. The cases selected for analysis were control modes specified in flight planning documentation or candidate control modes which are being considered for experiment support. Of the total set of control modes which will be utilized for experiment support, only those which are of an off-nominal or with special and/or distinct characteristics were selected for simulation in this study. For that reason, for some cases only one phase of an experiment may have been simulated if the experiment had several parts. The table below summarizes which part of the applicable experiment this study addresses:

CASE	EXPERIMENT	EXPERIMENT PHASE STUDIED
1	Stratospheric Aerosol Measurement (MA007)	All
2	Multipurpose Furnace (MA010)	Sample processing during docked operations
3 and 3A	Multipurpose Furnace (MA010)	Sample processing during docked operations
4	Soft X-ray (MA048)	Plane scans for celestial x-ray emission
5	UV Absorption (MA059)	Measurement of atmospheric gas pile up
6, 6A, 6B	Doppler Tracking (MA089)	Tracking phase after achieving separation distance
7	Artificial Solar Eclipse (MA148)	Separation sequence

For each experiment phase simulated, the vehicle was initialized to an attitude (LH reference) which was close to the planned attitude as specified in Reference 4, in order to reasonably simulate gravity gradient and aerodynamic torques. No attempt was made, nor was it important to exactly duplicate attitude or trajectory conditions. As such, these studies should be considered a general analysis based primarily on early mission planning documentation. New documentation which is applicable to this study will continue to be reviewed. If conditions are found to have changed sufficiently to invalidate the conclusions associated with a particular section, the simulation will be rerun and an update issued to this report.

ANALYSIS OF CASE 1

"Objective"

To demonstrate CSM/DM capability to stay within experiment MA007 rate limits (< .03°/sec) during a 120 second data take period when in "free" mode and under the influence gravity gradient torques.

"Test Sequence"

The simulation was initialized in the CMC auto mode with a small 10, 8, and 5 degree roll, pitch, and yaw maneuver, respectively. The maneuver lasted for approximately 10 seconds. At 20 seconds with the vehicle now in attitude hold, single jet R, P, and Y was configured. This effected a minimum impulse limit cycle which resulted in the smallest residual rates achievable while under auto control (≈ 0.005°/sec). At 150 seconds the control system was turned off (free mode) and the CSM/DM stack drifted for the remainder of the run. From Figures 1 through 3 it can be seen that the highest rate which developed was 0.02°/sec in pitch at the end of the 120 second data take period.

"Conclusion"

Based on the simulation data, it appears that the sun will remain within the MA007 10 degree field of view (FOV) during the 120 second data take period with all thrusters off. The sun is initially placed within the two degree target ring, which allows in the worse case, four degrees of sun movement in the 10 degree FOV during the data take period. Simulation results indicate the maximum sun movement due to vehicle angular rates during the data take period will be approximately 1.5 degrees.

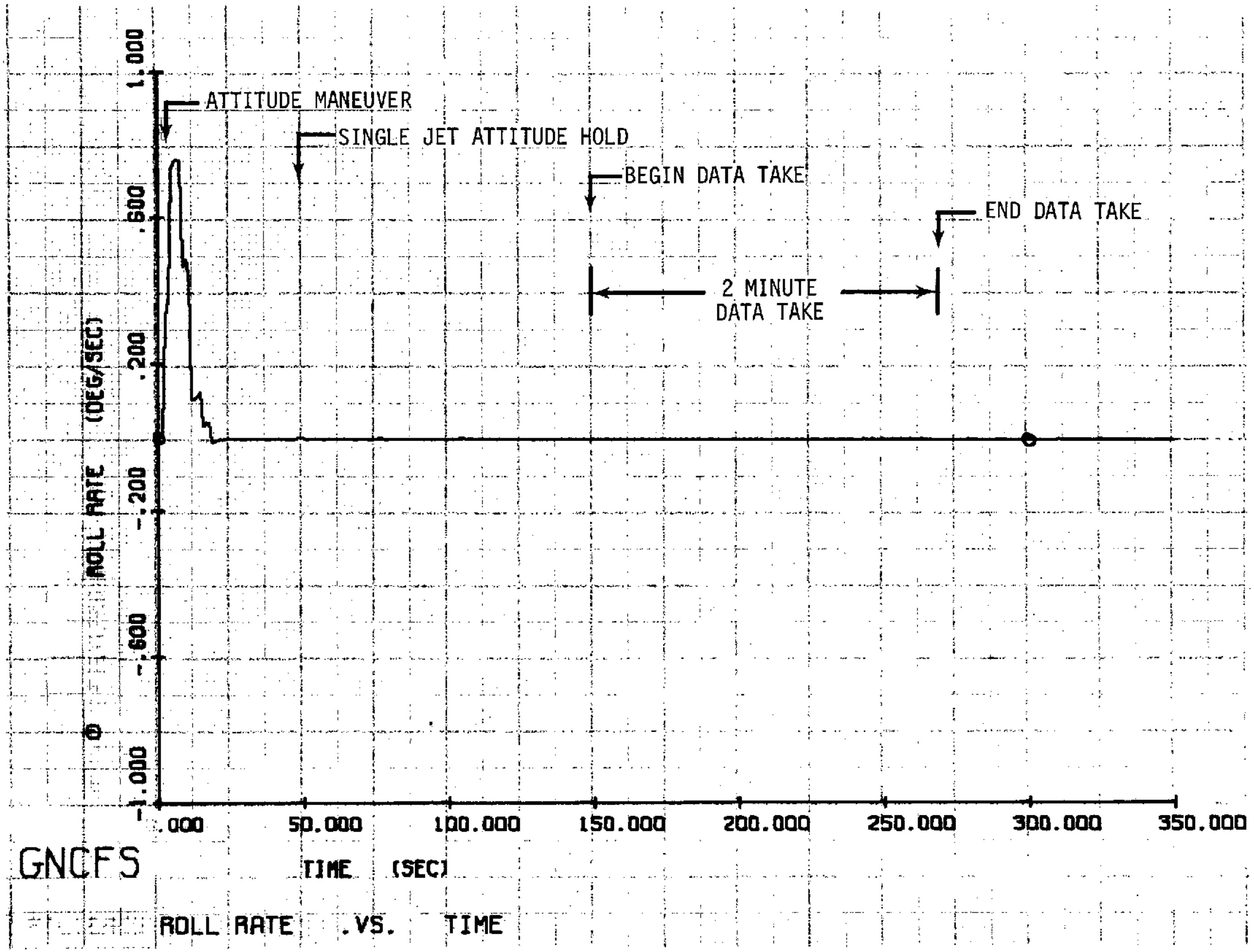


Figure 1. Case 1 - Roll Body Rates

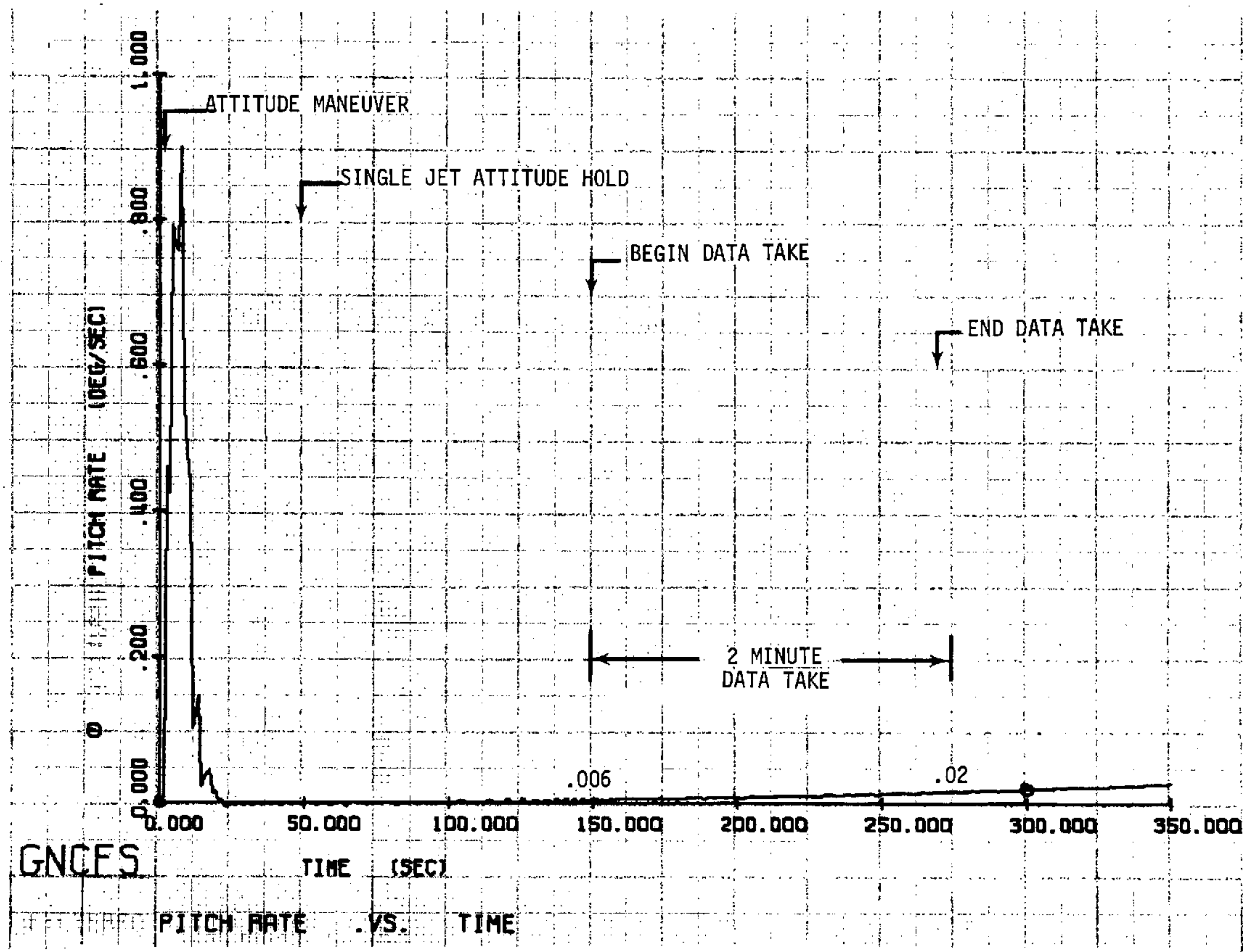


Figure 2. Case 1 - Pitch Body Rates

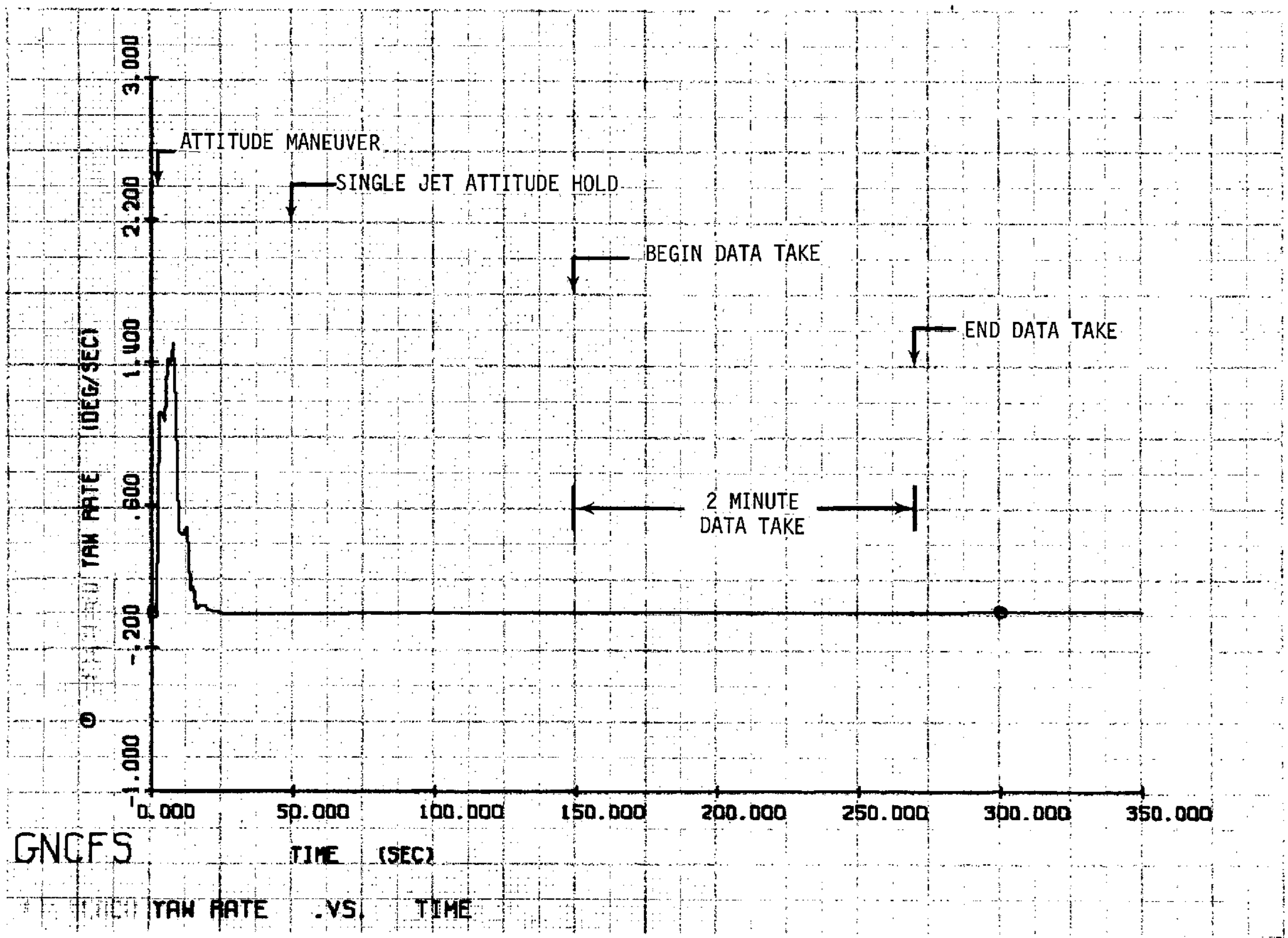


Figure 3. Case 1 - Yaw Body Rates

ANALYSIS OF CASE 2

"Objective"

To evaluate attitude hold capability of the RCS Docked DAP when configured for force mode and with the DAP configured for minimum angular acceleration in support of the MA010 experiment.

"Test Sequence"

The simulation was initialized in the CSM/DM/Soyuz configuration and with a planned 10, 8, and 5 degree pitch, yaw, and roll maneuver, respectively. All forward firing jets were disabled in accordance with Soyuz heating constraints. The force mode DAP was in effect. The maneuver was complete at approximately 20 seconds and with the vehicle in 5 degree deadband inertial attitude hold, a DAP load was provided to disable Quad C and D jets. This was done to provide one jet roll control, since two jet roll control accelerations exceed the experiment constraint limits. As a consequence, however, pitch and yaw control was reduced to single jet because force mode jet selection also uses the roll jets. An immediate alarm was generated on the DSKY in accordance with software design warning that spacecraft roll was impaired. The Docked DAP software is designed to time sequence paired firings during pitch or yaw control in order to account for roll torques resulting from c.g. asymmetry. Without two uni-directional jets available, this time sequencing is impossible and the roll control function is bypassed. In concurrence with software design, the Docked DAP continued to control pitch and yaw within the 5 degree deadband (Figures 4 and 5). The vehicle remained out of control in roll drifting at approximately 0.1°/sec for the first 4300 seconds of the run. The vehicle did not accelerate in roll because the pitch and yaw attitude errors were both positive and near the deadband resulting in jet firings which cancelled each other's roll torques. After 4300 seconds, the P and Y attitude errors drifted to a point where the RCS firings for P and Y control were in the same direction in terms of roll torque and the vehicle gradually accelerated in roll (see Figure 6) attaining a rate of approximately 10°/sec when the simulation ended at 5400 seconds. The fuel consumption for P and Y control was 13 lbs/orbit.

"Conclusion"

This mode degrades to conditions which are intolerable. A low level uncontrolled roll rate would possibly be acceptable but the high rates which developed after 4300 seconds cannot be tolerated. In addition, the high angular body rate would produce a radial acceleration at the experiment, because of experiment location offset from the vehicle center of gravity, which would exceed experiment acceleration limits.

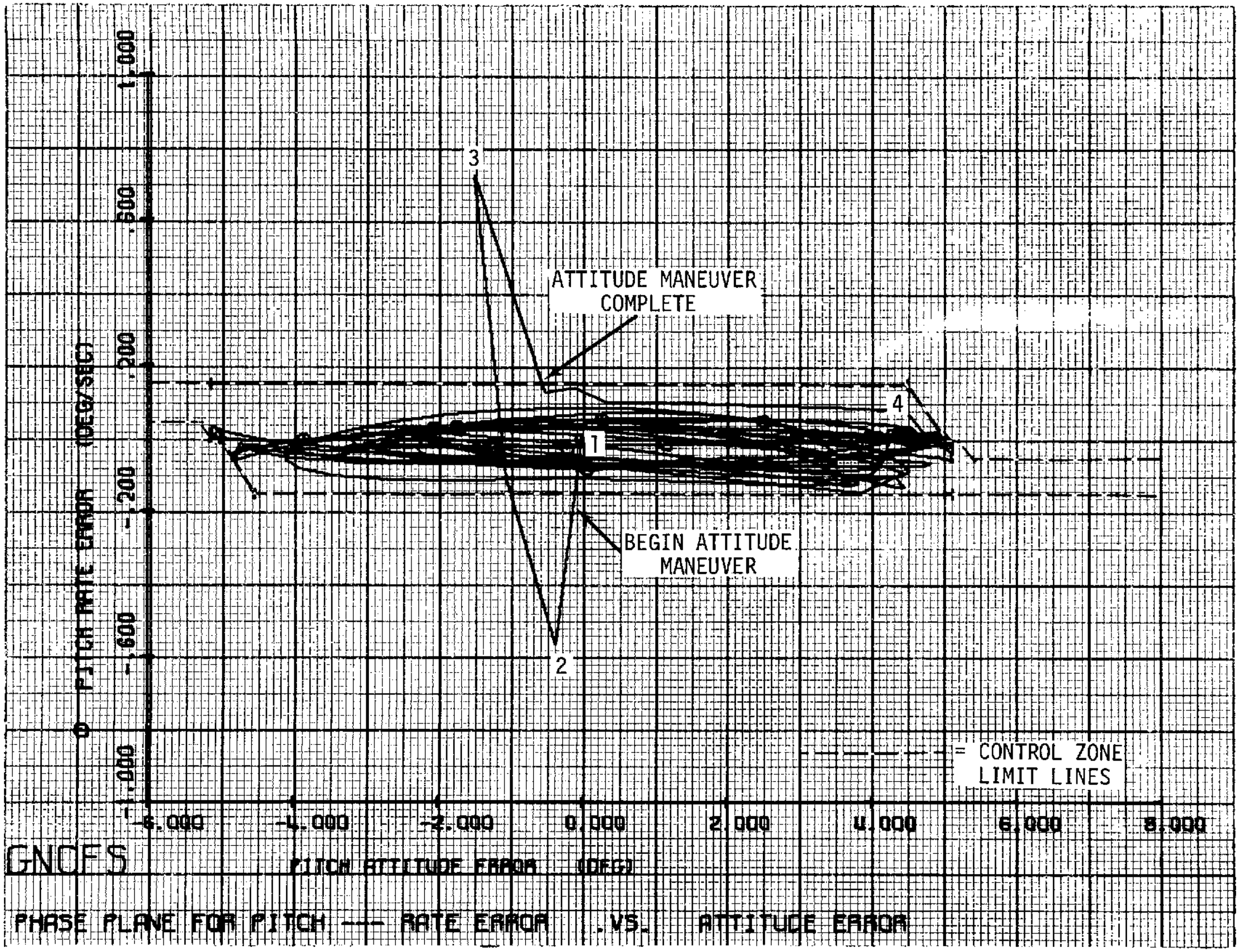


Figure 4. Case 2 - Pitch Axis Phase Plane

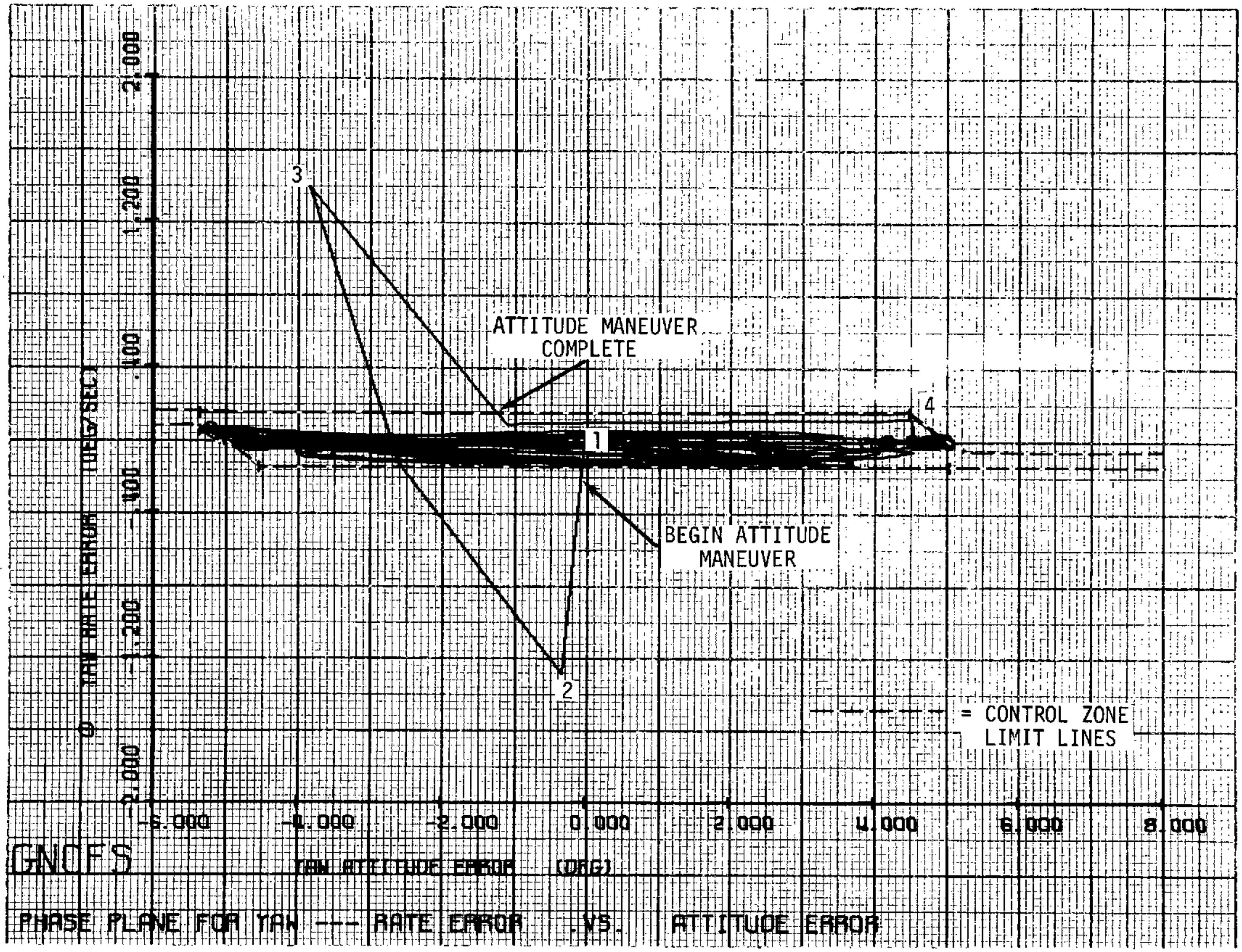


Figure 5. Case 2 - Yaw Axis Phase Plane

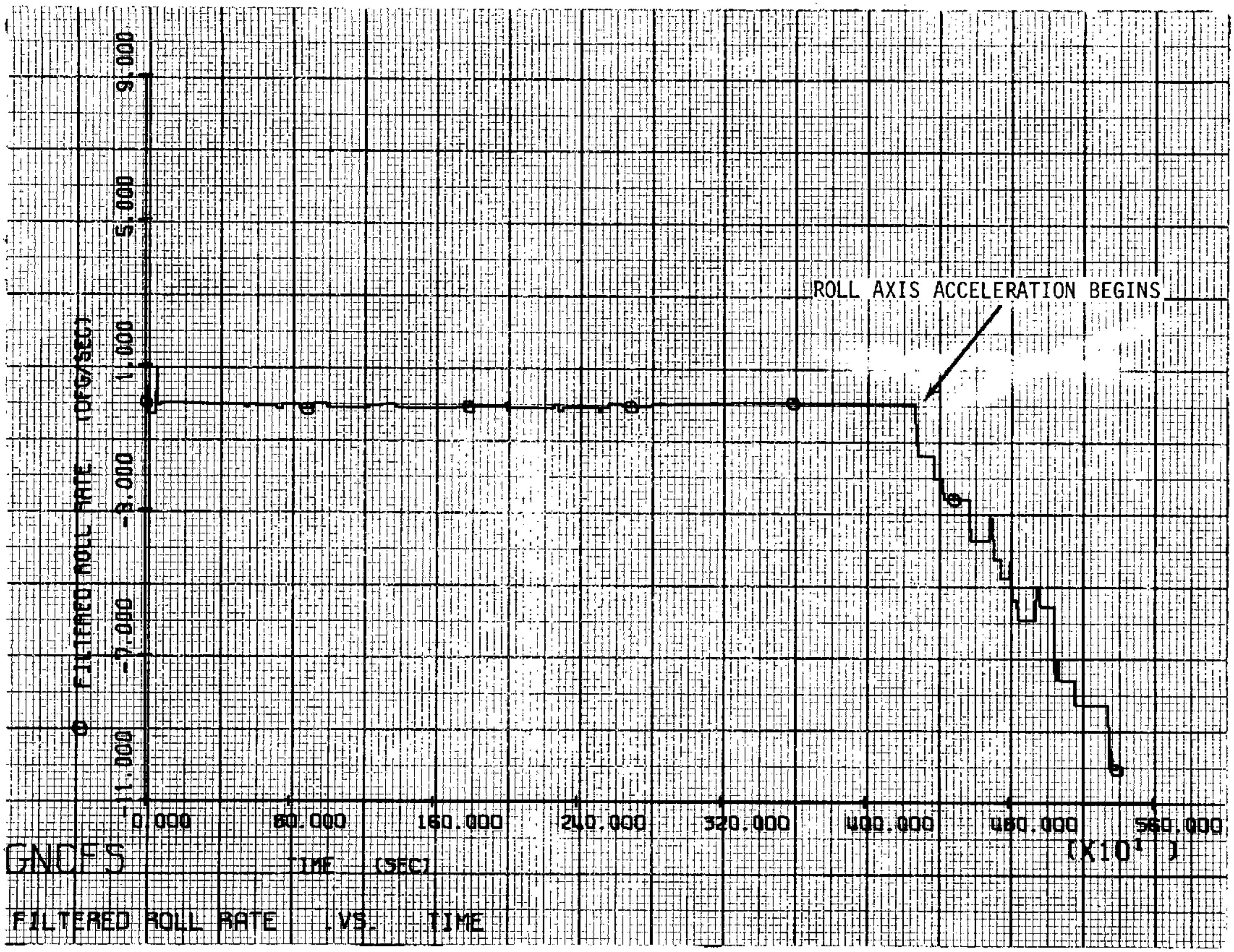


Figure 6. Case 2 - Roll Axis Body Rate

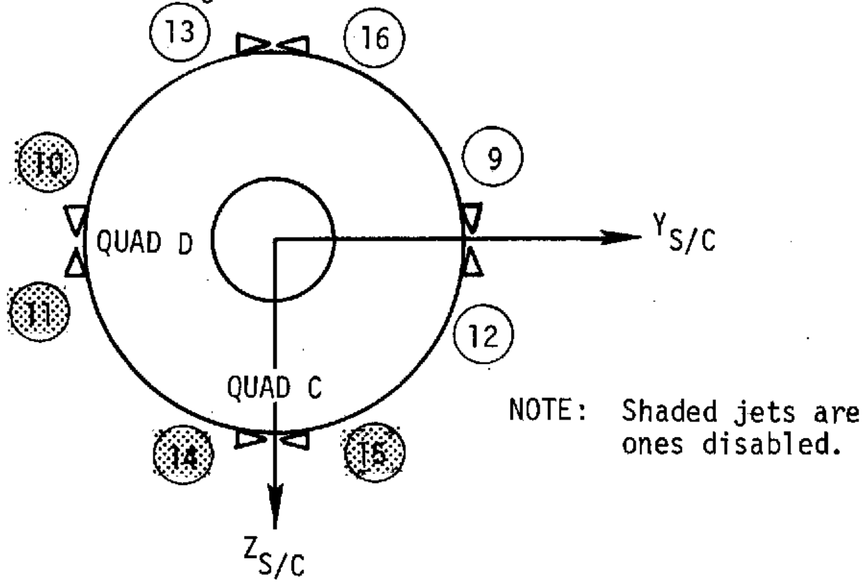
ANALYSIS OF CASE 3 AND 3A

"Objective"

To evaluate attitude hold capability of the RCS Docked DAP with the RCS jets configured for minimum angular acceleration in support of the MA010 experiment.

"Test Sequence"

Simulation Case 3 was initialized with the CSM/DM/Soyuz configuration and a planned 10, 8, and 5 degree pitch, yaw, and roll maneuver, respectively, at the simulation start. All forward firing jets were disabled in accordance with Soyuz heating constraints. The force mode DAP was in effect. The maneuver was completed at approximately 20 seconds, and with the vehicle in 5 degree deadband inertial attitude hold, a reconfiguration of the RCS thrusters was applied which disabled the Quad C and D roll jets. This was done to provide one jet roll control, since two jet roll control accelerations exceed the experiment constraint limits. As a consquence however, P and Y control was reduced to single jet because force mode jet selection also uses the roll jets. The net result was attitude control of the stack using a total of four thrusters. The jet disabling was done external to the DAP (simulating use of RCS select switches) which avoided the alarms and the disabled roll control experienced in Case 2. The Docked DAP continued to control in all axes calling for two jet control but getting only one jet firing. The Docked DAP properly controlled in P, Y, and R for approximately 10 minutes. During the early part of the run, the attitude errors were such that 3 axis control was being accomplished with Jets 13 and 12 of the four available jets as shown in the figure below:



Roll control is degraded with the Jet 12 and 13 combination, but the roll is not diverging either. At approximately 700 seconds of the run, the attitude errors had changed such that a third jet, Jet #16, was needed to control yaw attitude and this caused a problem. Although 13 and 16 are not allowed to fire simultaneously, they can fire in succession. Because the software services P and Y before roll, the 16 and 12 jets were fired followed by a Jet #13 firing for roll control. With the roll control firing overridden by the pitch and yaw firings, the result is an eventual loss of control about the roll axis. As shown in Figure 7, the roll rate built to approximately 0.3°/sec. The pitch and yaw errors for the most part remained within the control limits.

Simulation Case 3A was set up the same as above except the Docked DAP coupled mode was requested. A maneuver was programmed in at the simulation start to provide some realistic rate and attitude errors. At 20 seconds a 5 degree deadband inertial attitude hold mode was begun. Also at 20 seconds, all forward firing thrusters, the two thrusters pointing in the positive Y spacecraft direction, and the two thrusters pointed along the positive Z axis were disabled external to the DAP (simulating use of RCS jet select switches). Now attitude control of the stack was being accomplished with effectively six jets. The Y and Z direction jets were disabled to effect single jet roll control. As shown in Figures 8 through 10, the DAP maintained control in all three axes during the 90 minute simulation period. The figures show the pitch and yaw errors settled out against the positive deadbands but the roll error continued to limit cycle across the deadband. Fuel cost for this mode was about 14 lbs/orbit. Normal configuration Docked DAP force mode inertial attitude hold in 5 degree deadband requires approximately 2 lbs/orbit.

"Conclusion"

Single jet force mode Docked DAP is not a viable control option in support of Experiment MA010 because of the uncontrolled roll rate which develops. Single jet coupled mode Docked DAP is a workable control mode; however, with the current DAP software parameters the fuel cost to provide this off-nominal configuration is expensive. Since the MA010 experiment will run for about 29 hours when in the docked configuration, it is impractical to consider this fuel penalty for such a long period of time. By tailoring the

DAP software parameters to account for the one jet P, Y, and R configuration, it is possible to improve the DAP performance and diminish the fuel consumption rate. Consideration of the alternative will require (1) additional DAP analysis to establish and verify the new DAP parameters and (2) evaluation of the operational aspects involved in loading the modified parameters into the CSM computer during the docked flight phase.

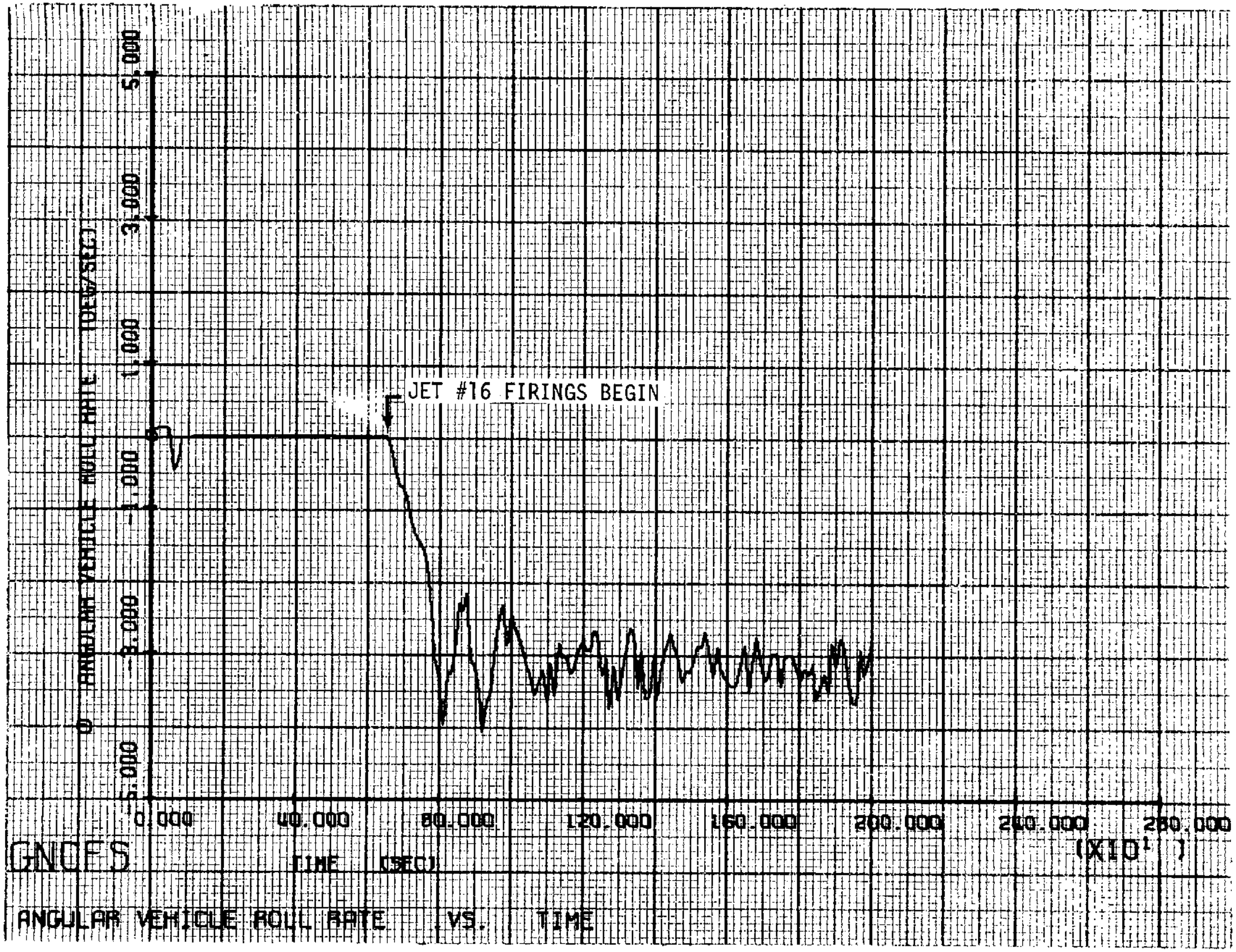


Figure 7. Case 3 - Body Roll Rate

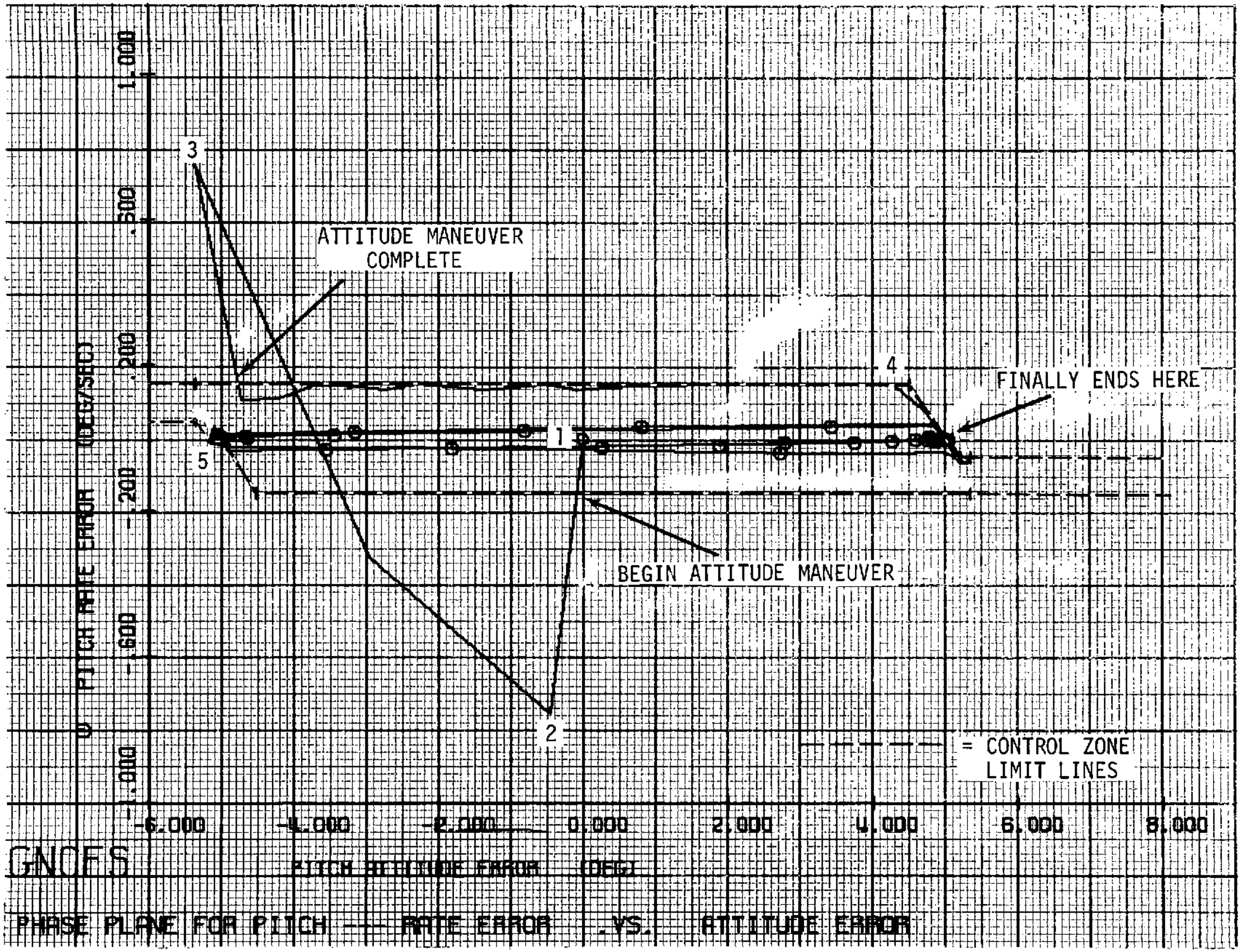


Figure 8. Case 3A - Pitch Phase Plane

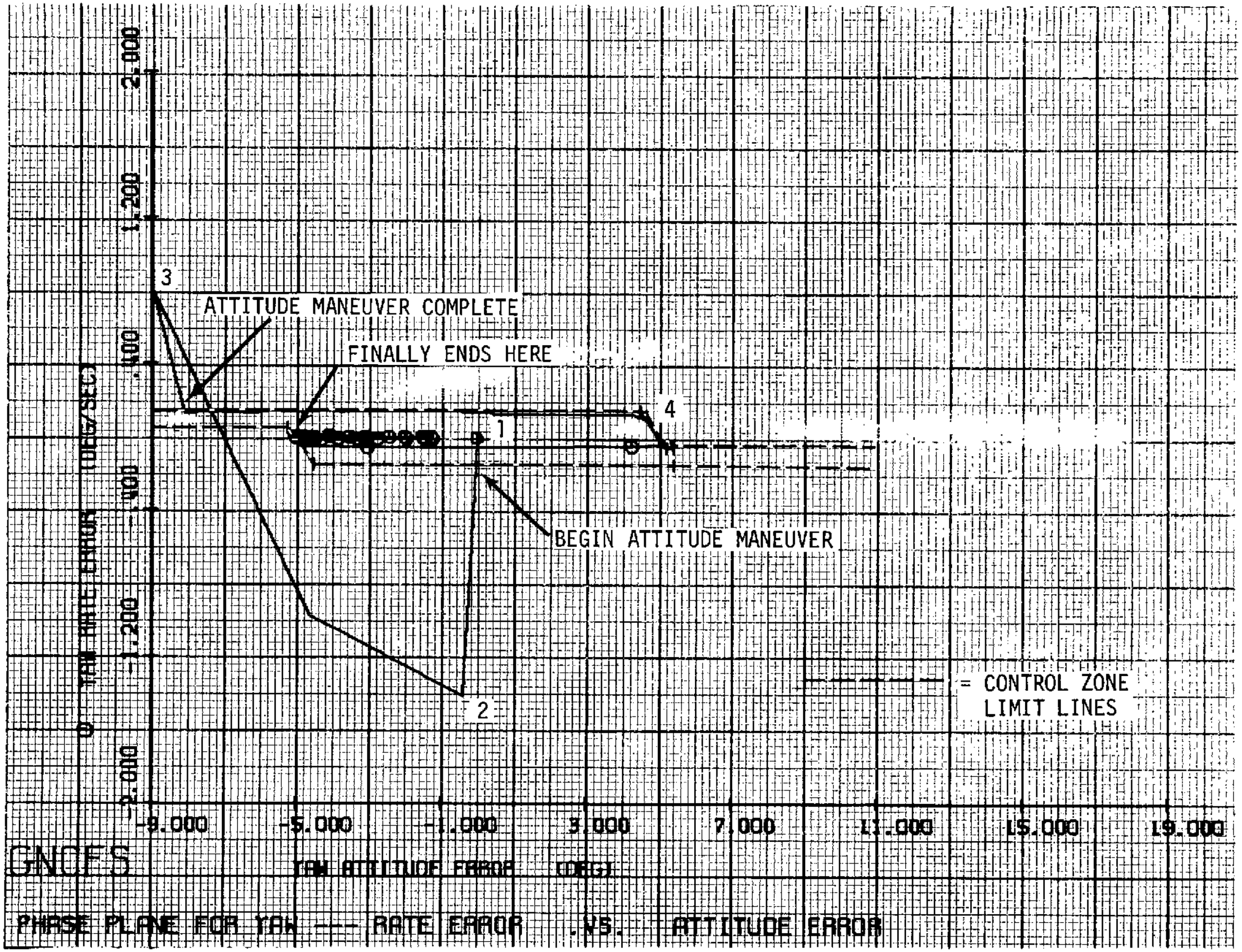


Figure 9. Case 3A - Yaw Phase Plane

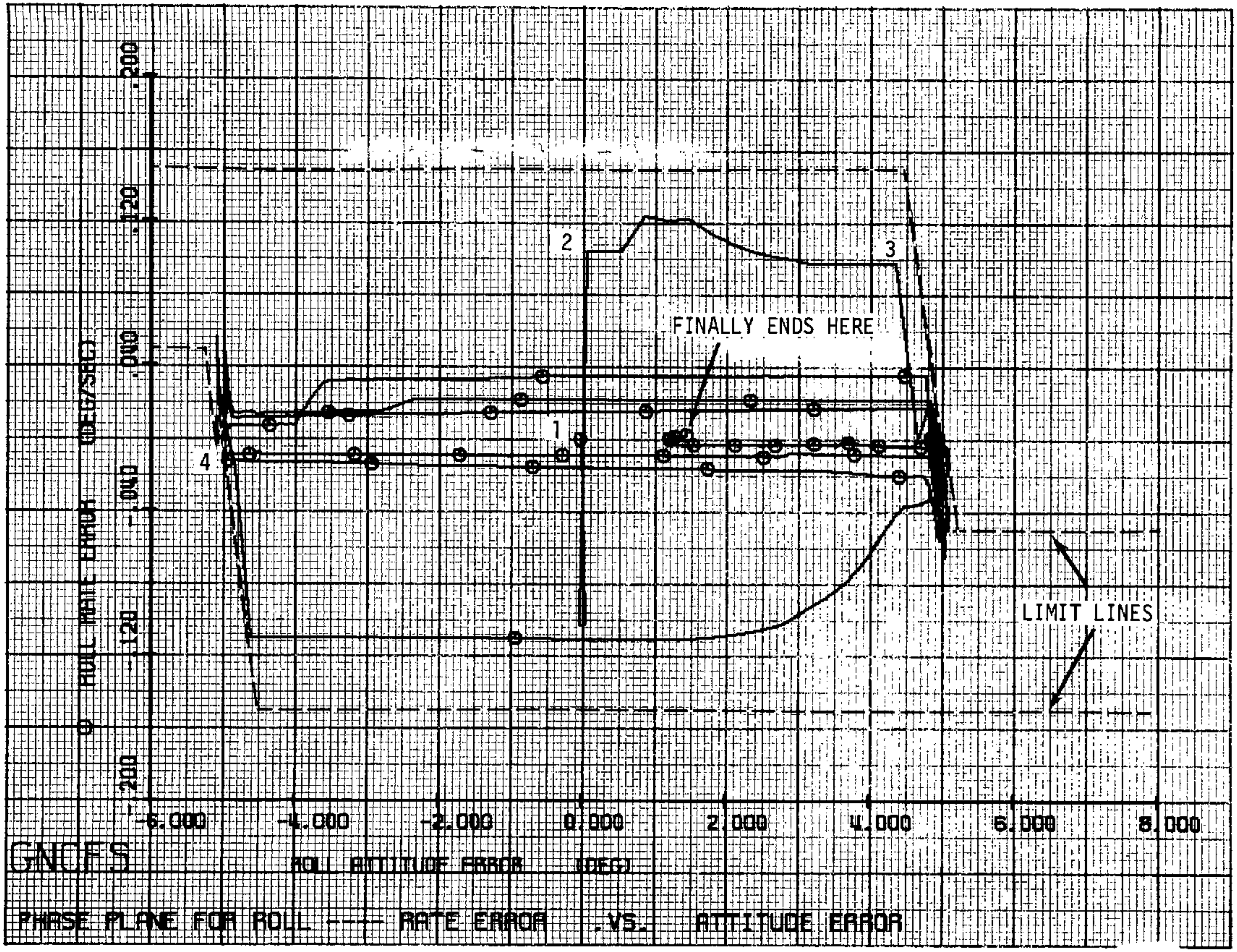


Figure 10. Case 3A - Roll Phase Plane

ANALYSIS OF CASE 4

"Objective"

To evaluate the capability of pointing the Service Module experiment bay in a desired direction and then rotating about the spacecraft X axis to effect a sweeping motion for the experiment bay Line-of-Sight (LOS) in support of the MA048 experiment.

"Test Sequence"

The simulation was initialized with the vehicle in the local horizontal attitude and 0.5 degree deadband attitude hold. A 90 degree pitch maneuver was programmed immediately after simulation start to place the spacecraft X axis perpendicular to the orbit plane. The maneuver was completed after about 50 seconds. The vehicle was maintained in attitude hold for 60 seconds after completing the maneuver to damp the body rates, and at 110 seconds the vehicle was accelerated to a 0.3°/sec rate about the X axis. After attaining the desired roll rate, RCS thrusters A2, A4, B1, and B4 (the thrusters which would emit particulates into the MA048 field of view) were disabled simulating use of the RCS jet select switches. Figures 11 through 13 show the vehicle body rates during the run. After 20 minutes of rolling and maintaining 0.5 degree deadband in pitch and yaw, the roll rate was terminated. The vehicle rate data shows the roll rate oscillating between 0.275 and 0.34°/sec and the yaw rate oscillating between ±0.01°/sec. This translates into a spacecraft wobble of approximately 4 degrees which means an experiment LOS directional error of 2 degrees due solely to the imperfections in the rotational control. Figure 14 and 15 show the P and Y phase plane results for the run and indicate rate and attitude errors were properly maintained within the bounds of the limit lines.

Data indicates approximately 0.9 lb of RCS fuel required to start the body rate, hold attitude in P and Y for 1200 seconds, and stop the body rate. Since the minimum experiment requirement is three scans with a highly desirable requirement for seven additional scans, RCS fuel required for this part of the experiment will range from approximately 3 to 9 lbs.

"Conclusion"

The P20 Option 2 mode operating at 0.3°/sec, narrow deadband, and with 4 jets disabled provides acceptable control for the MA048 experiment during the planned scan mode. No requirements were available for experiment LOS accuracy during the scan mode so it is assumed that the LOS variation due to spacecraft wobble will not adversely affect data collected during the celestial scans.

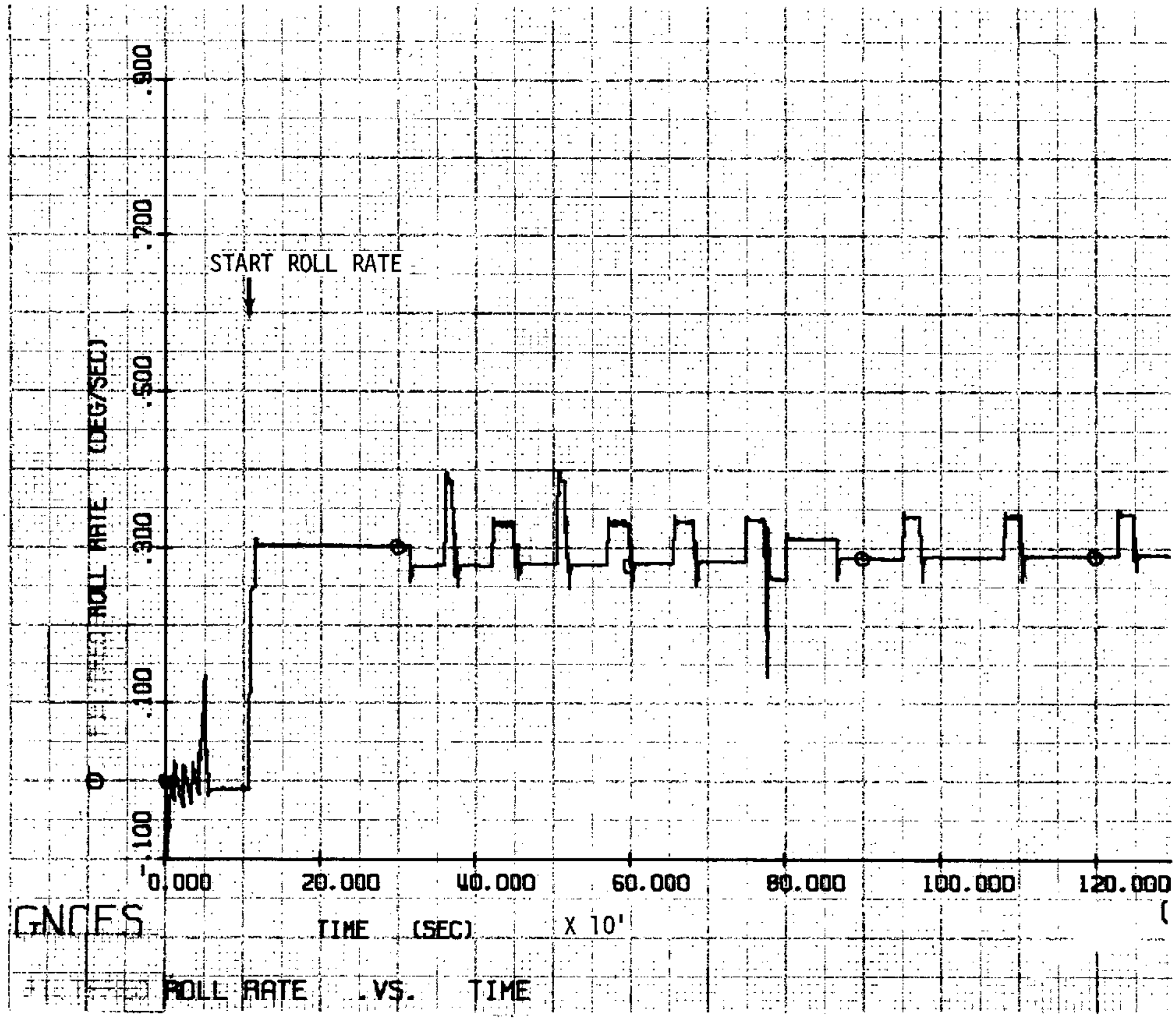


Figure 11. Case 4 - Vehicle Roll Rate

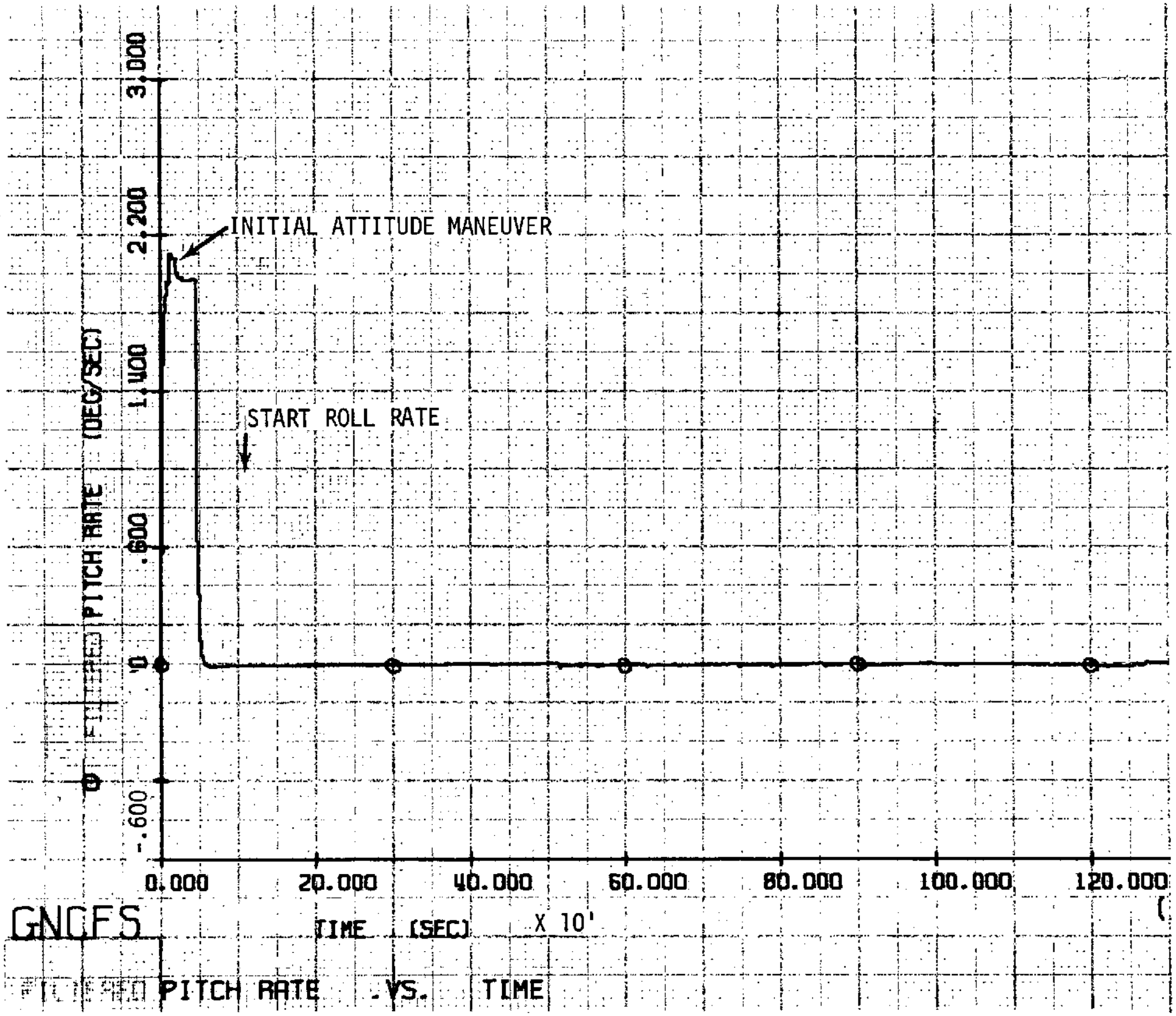


Figure 12. Case 4 - Vehicle Pitch Rate

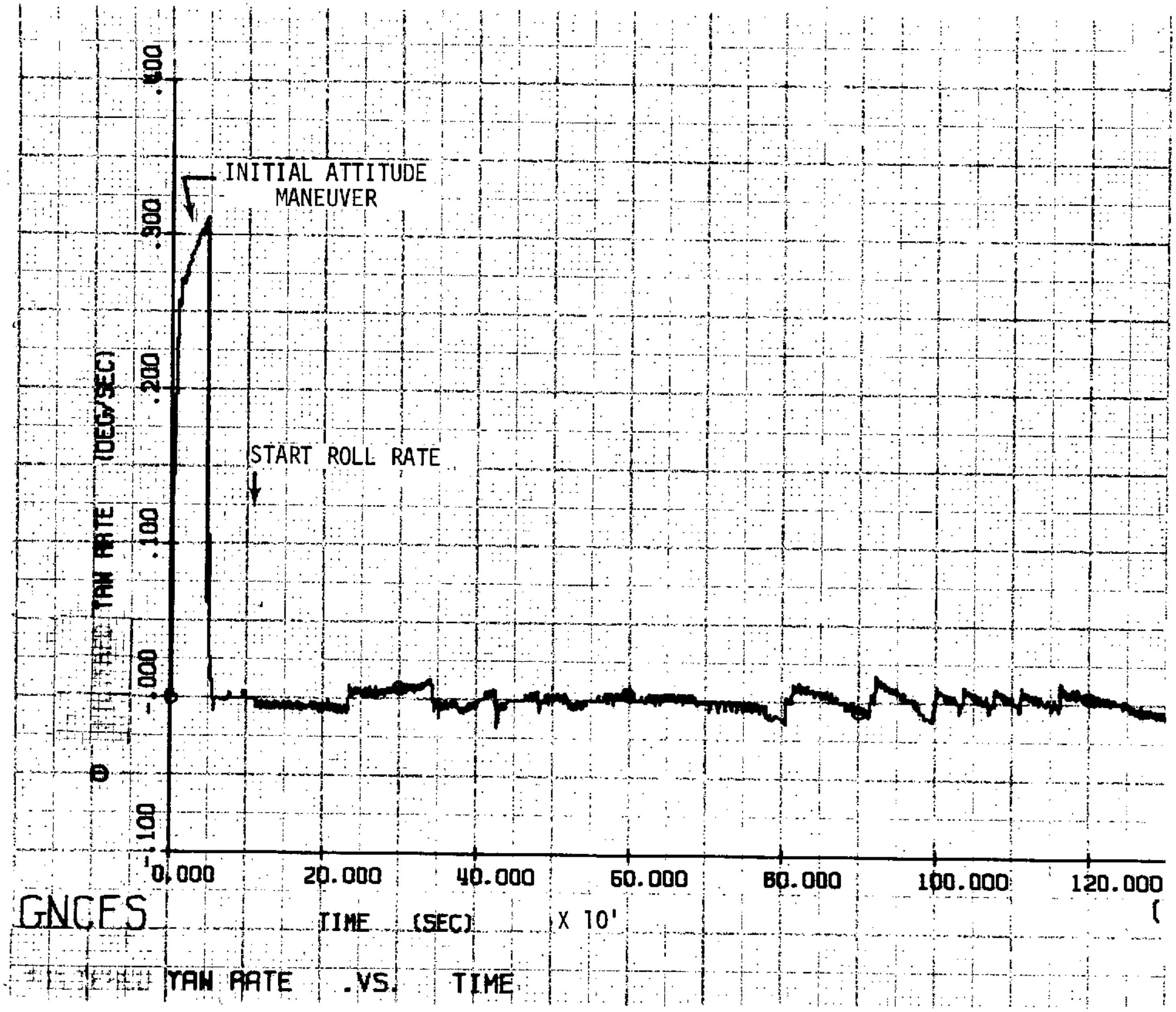


Figure 13. Case 4 - Vehicle Yaw Rate

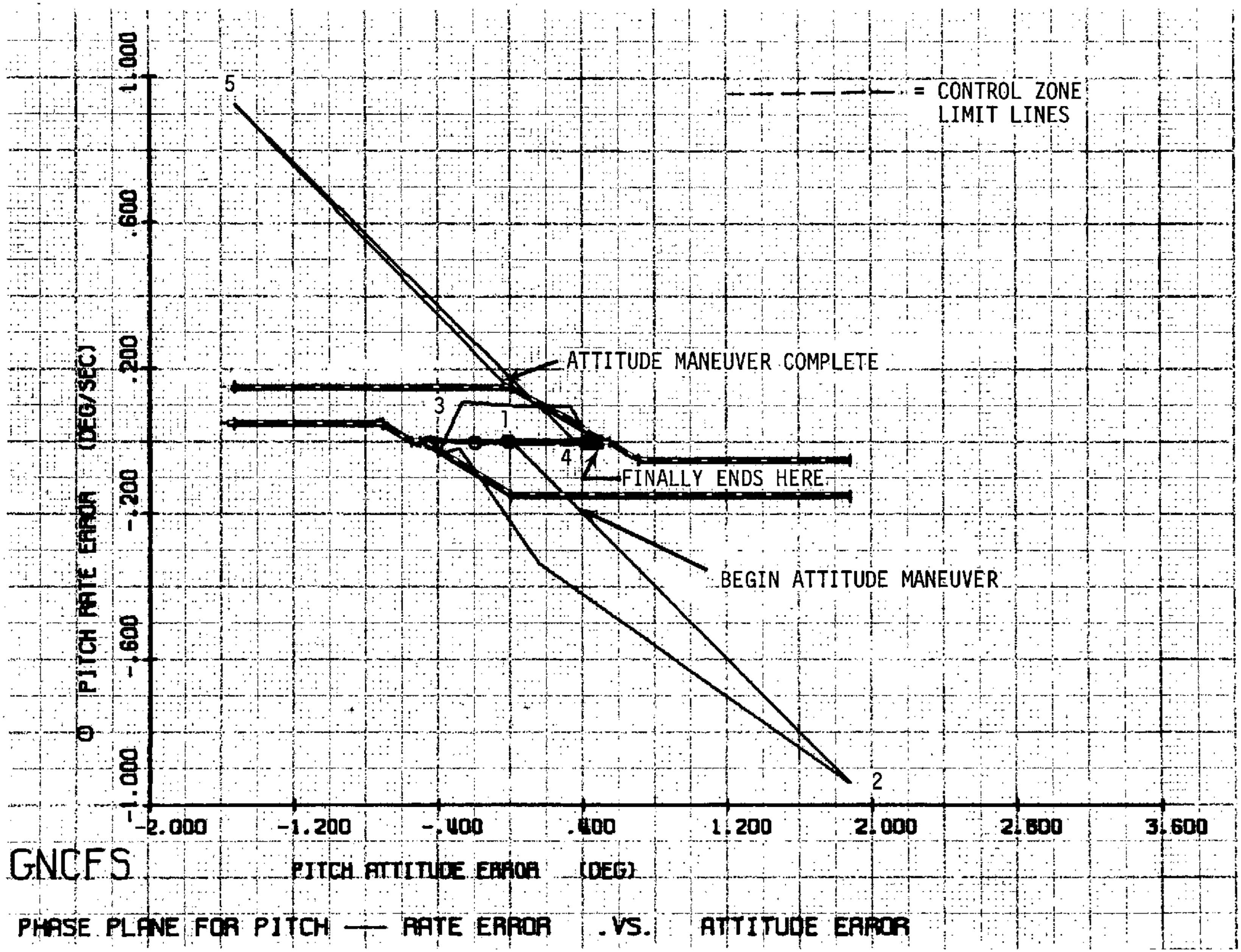


Figure . Case 4 - Pitch Phase Plane

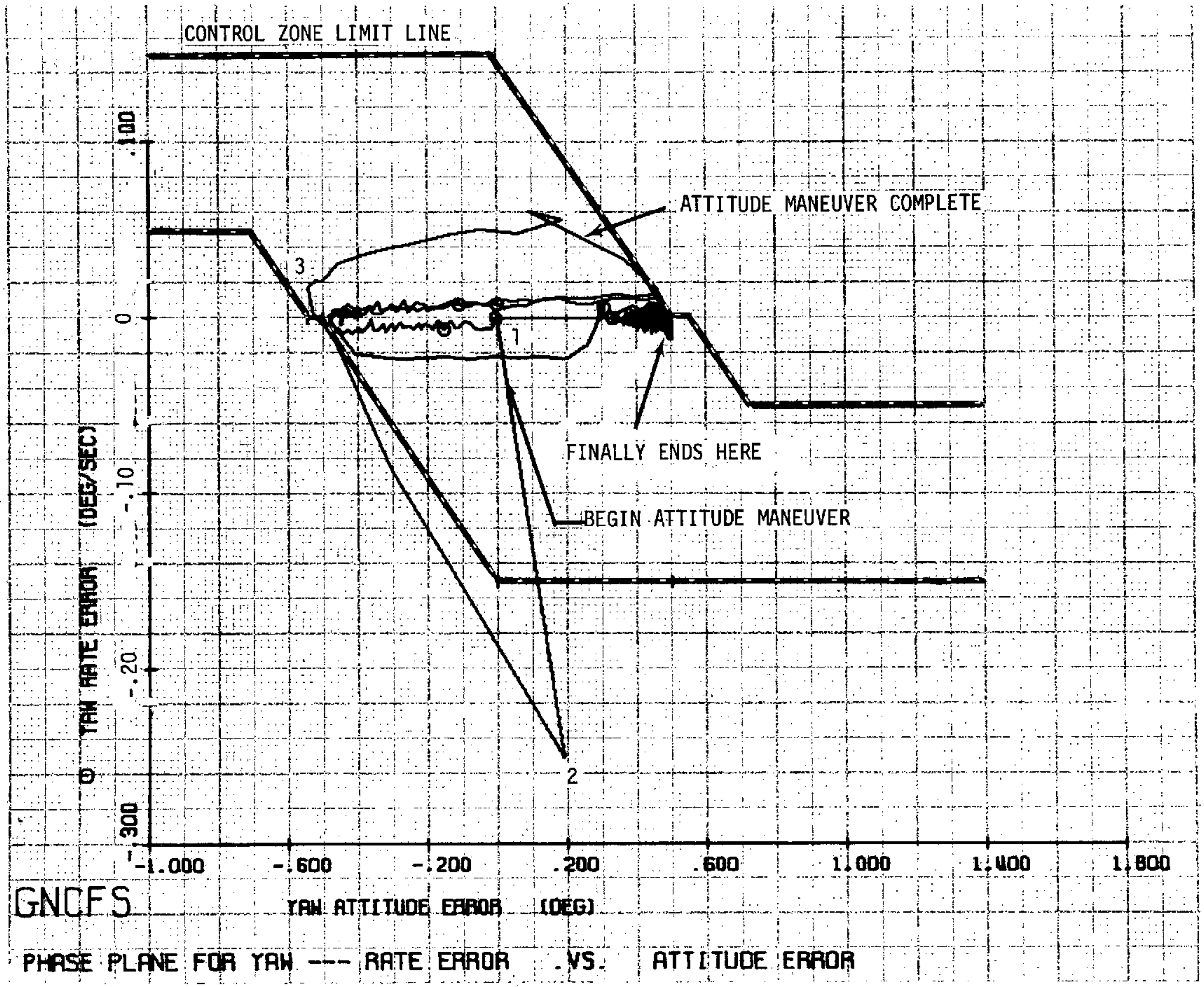


Figure . Case 4 - Yaw Phase Plane

ANALYSIS OF CASE 5

"Objective"

To evaluate the capability to point the spacecraft +X axis out of plane, initiate a roll rate, and maintain the desired P and Y attitude in the presence of gravity gradient and with selected jets off in support of experiment MA059.

"Test Sequence"

The simulation was initialized with the vehicle X axis out of plane and Z spacecraft axis outward along the radius vector. A small rate (0.02°/sec) was set into each spacecraft axis to simulate residual rates after completion of an attitude maneuver. A period of 100 seconds was allowed for damping the initial rates. At 100 seconds, the roll rate was accelerated to 0.5°/sec and also the forward firing thrusters A3, B3, D4, and C4 were disabled. The jets were disabled simulating use of the RCS jet select switches. Thrusters A3, B3, and D4 are mandatory inhibited jets during MA059 (to minimize particulates in the experiment field-of-view); the fourth thruster was disabled to provide a balanced one jet torque for positive and negative pitch commands. The vehicle was allowed to roll for one revolution (720 seconds). As shown in Figure 16 and 17, the attitude control system maintained the P and Y attitude errors within the 0.5 degree deadband limits throughout the rolling period. Figures 18 through 20 show the attitude rate histories for all three axes and the data indicates a varying average rate between 0.51 and 0.50°/sec for the roll axis and a varying rate of -0.005 to 0.0075°/sec and -0.0075 to 0.0075°/sec for pitch and yaw, respectively. From these data, it was determined that the vehicle wobbles through a cone angle of 2.2 degrees during the 360 degree roll maneuver.

"Conclusion"

The P20 Option 2 mode operating at 0.5°/sec, narrow deadband, and with A3, B3, C4, and D4 thrusters disabled provides acceptable control for the MA059 scan mode. No requirements were available for attitude accuracy during the scan mode so it's assumed the spacecraft wobble will not adversely affect the experiment data.

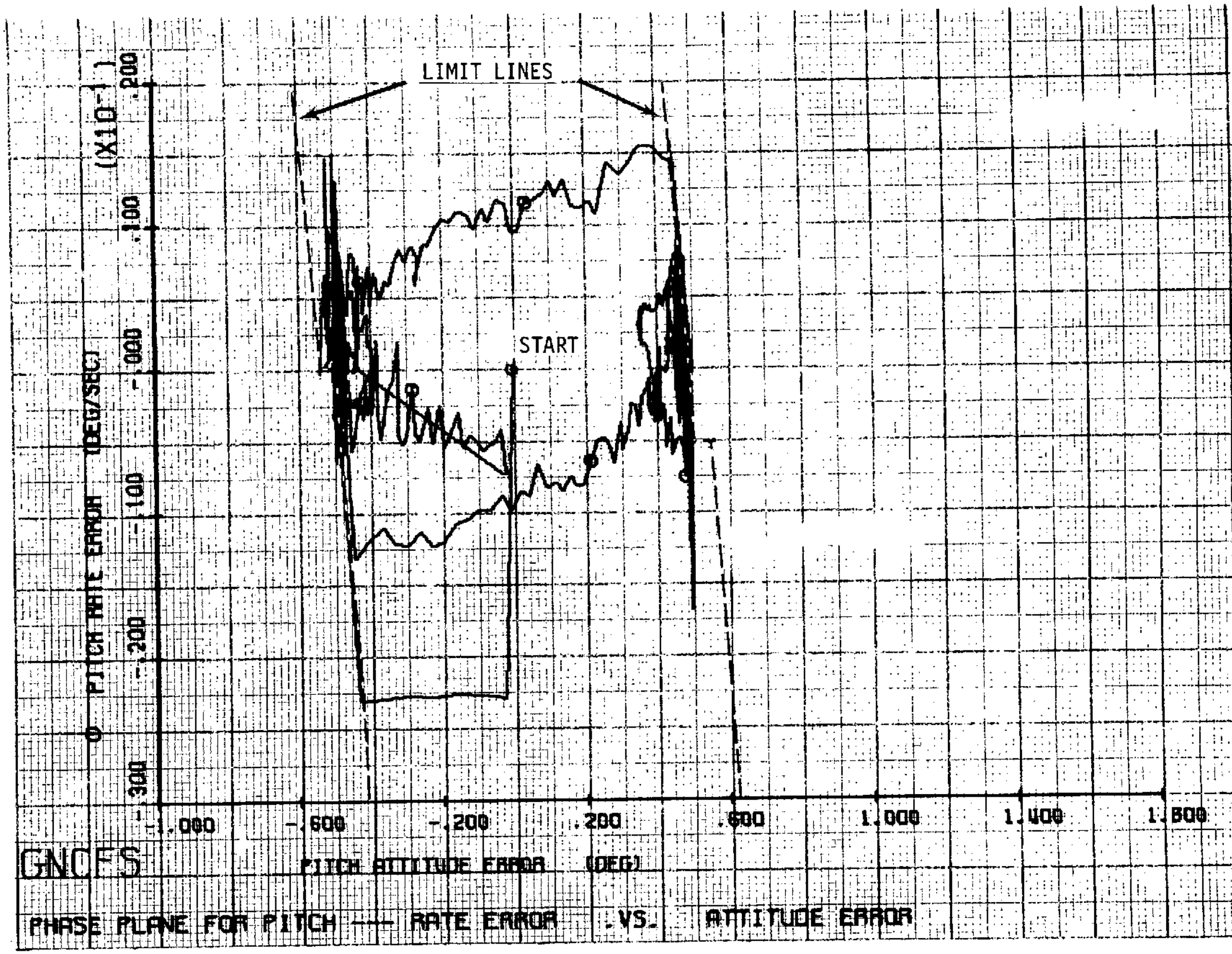


Figure 16. Case 5 - Pitch Phase Plane

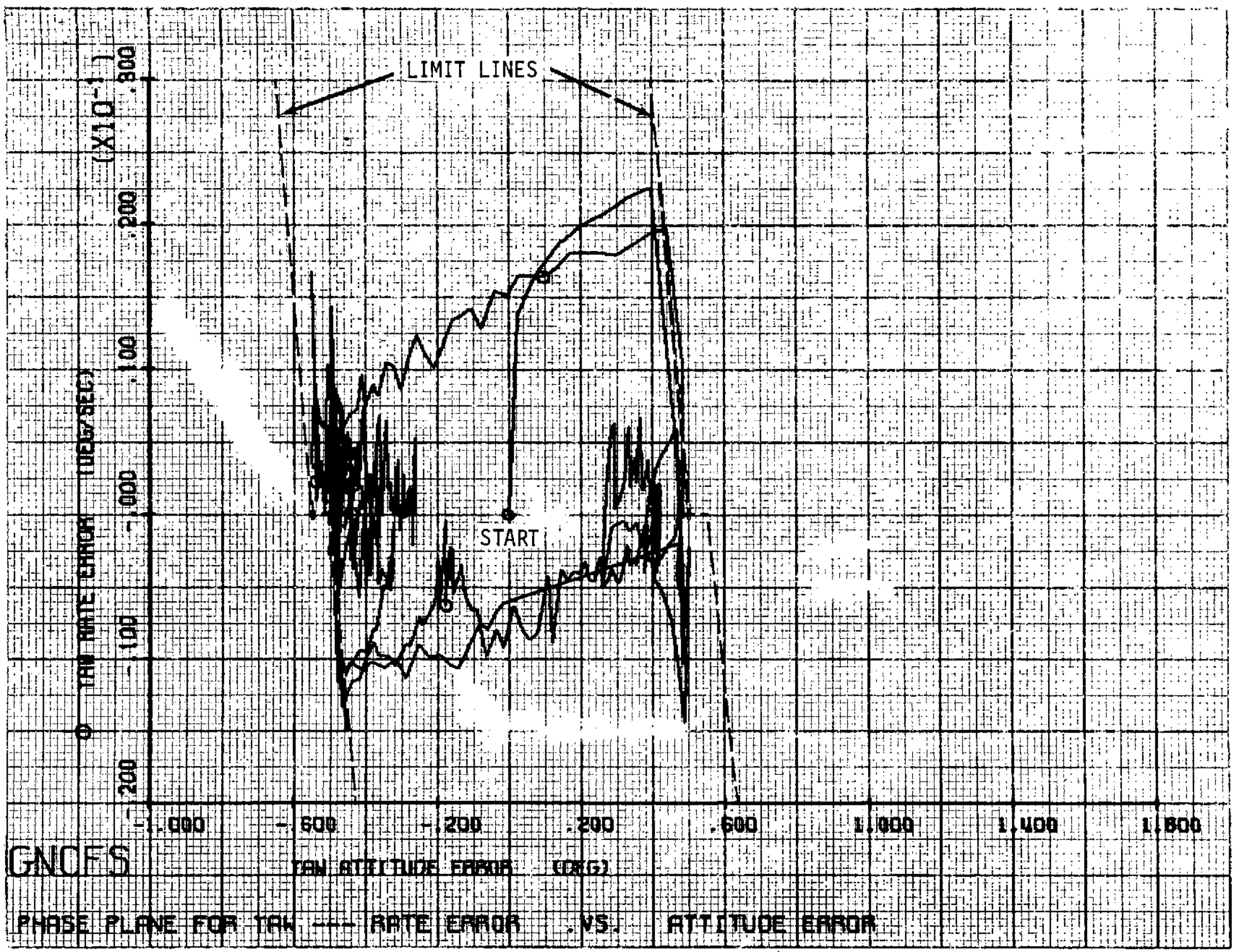


Figure 17. Case 5 - Yaw Phase Plane

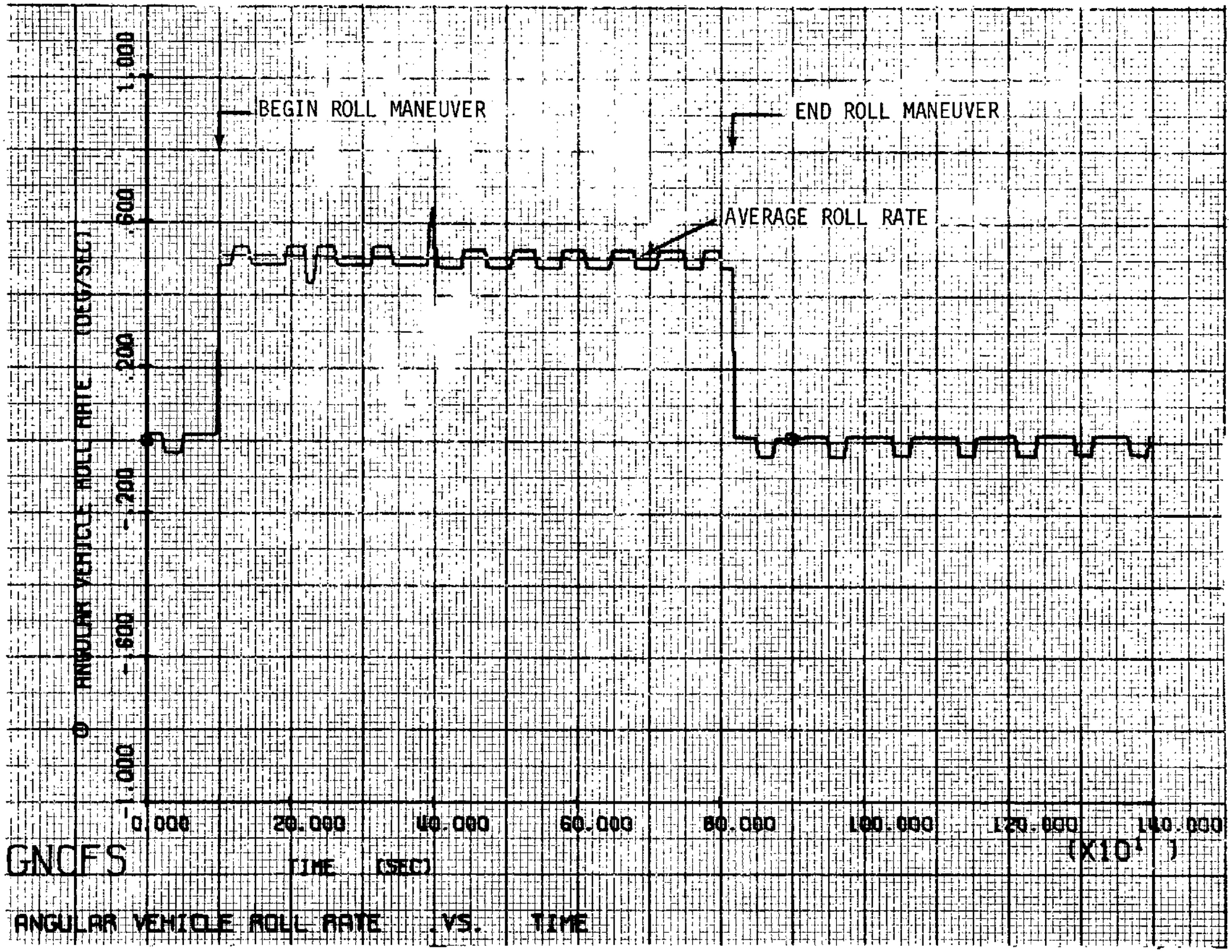


Figure 18. Case 5 - Body Roll Rate

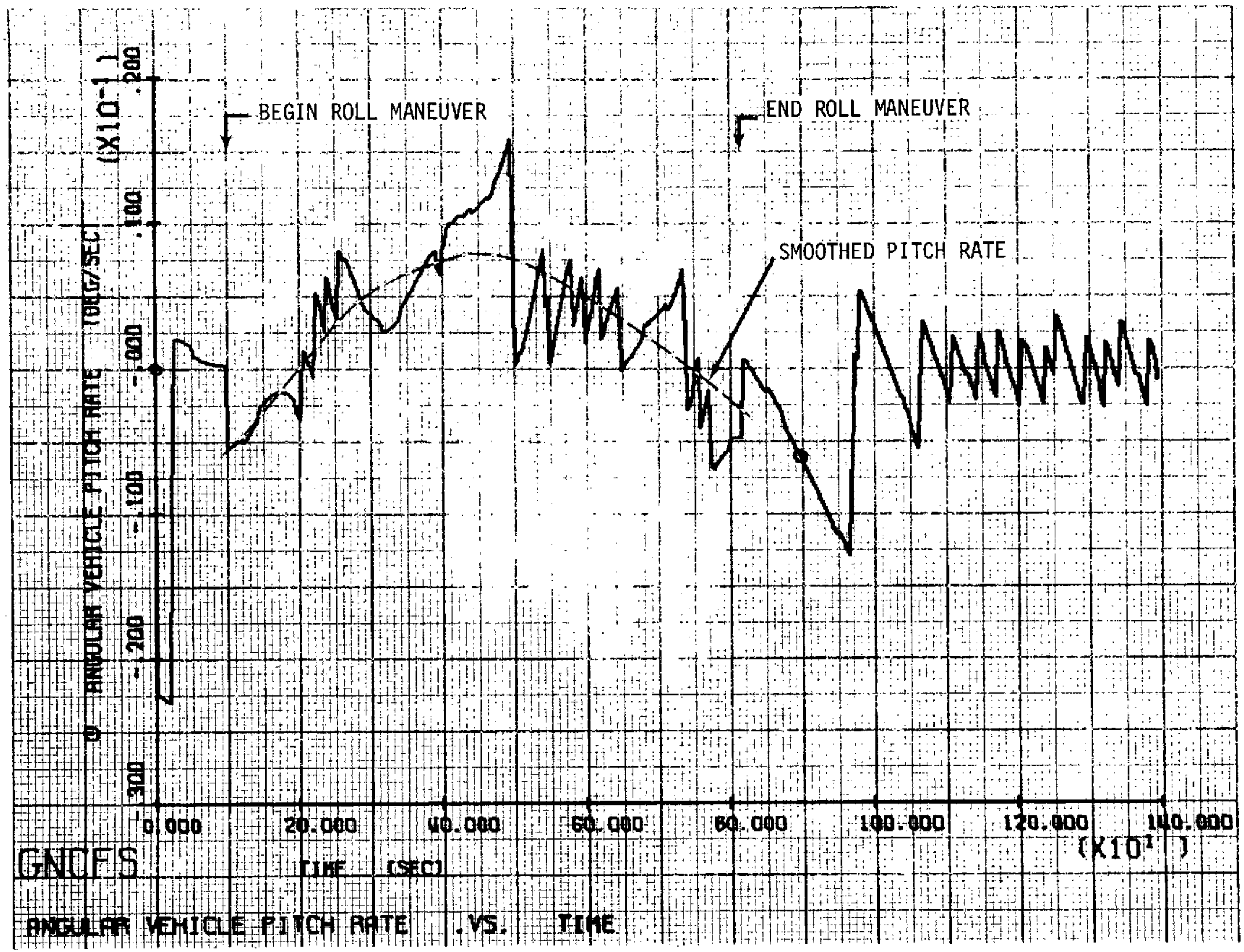


Figure 19. Case 5 - Body Pitch Rate

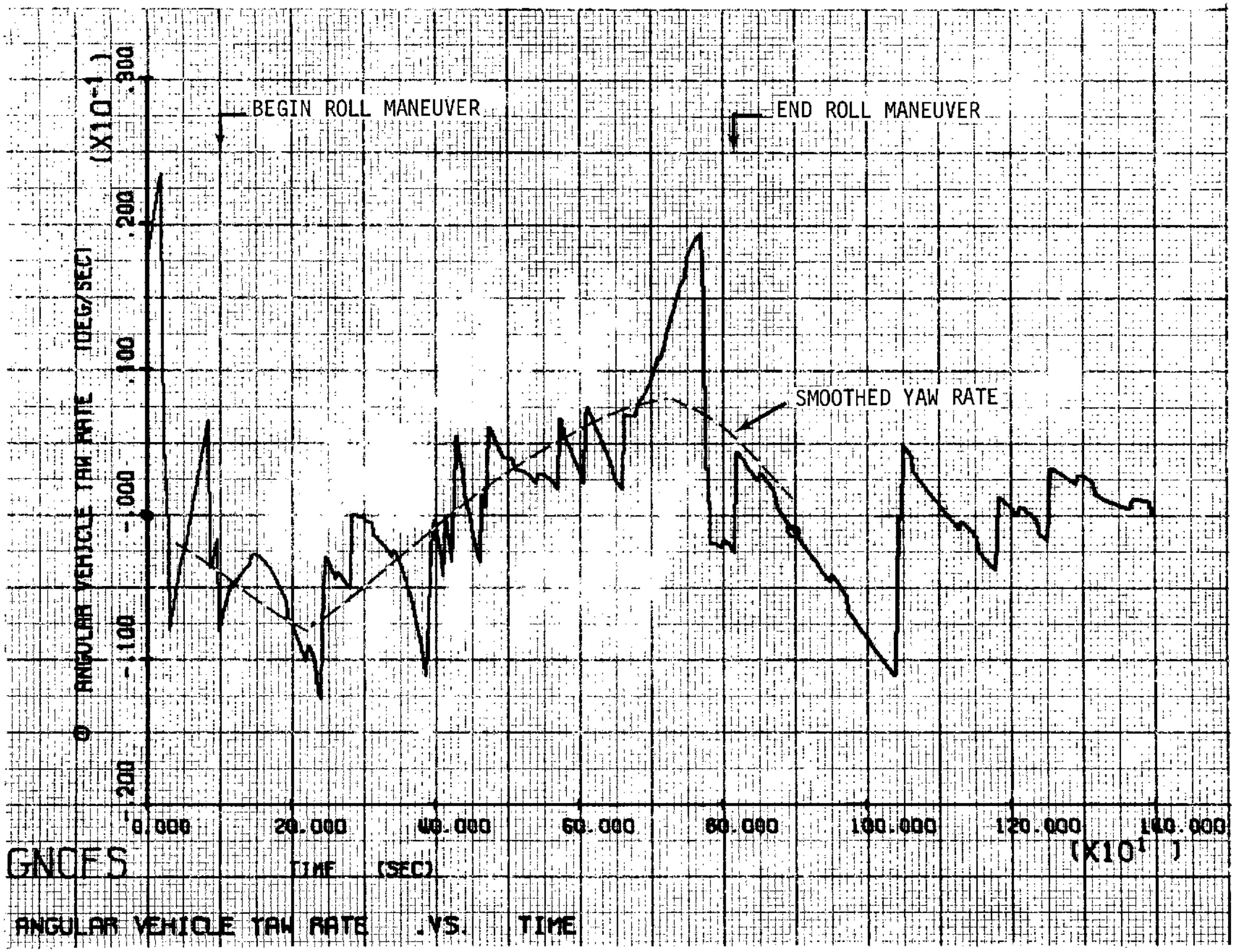


Figure 20. Case 5 - Body Yaw Rate

ANALYSIS OF CASE 6

"Objective"

To evaluate the resultant limit cycle and fuel usage when maintaining a fixed line-of-sight relative to local horizontal for nine orbits in support of MA089 post separation tracking of the docking module in the presence of gravity gradient torques.

"Test Sequence"

Three attitudes are under consideration for this experiment. The various attitudes were proposed due to the various attitude constraints and limitations imposed, i.e., maintain ATS-F coverage, minimize the reflected interference from the earth to the doppler antenna, and maintain the doppler antenna pointed in the direction of the jettisoned docking module (DM). The three general attitudes considered are summarized below:

CASE	ATTITUDE
6	X spacecraft axis down and 30 degrees off vertical and the Y and Z axis splitting the velocity vector.
6A	A spacecraft axis out of plane and the Y axis approximately downrange.
6B	X spacecraft axis up and 30 degrees off vertical, Z axis approximately out of plane, and Y axis pointing downrange.

For each tracking attitude a spacecraft vector was input to the P20 program which pointed toward the earth (Option 5), and the vehicle was commanded to maintain that vector pointed to the earth which in turn maintained the DM tracking attitude. This simulated tracking of the jettisoned DM which was assumed to be orbiting forward of the CSM. The exact local vertical angles used and the earth pointing vector loaded into P20 Option 5 are shown below:

	LH ATTITUDES (DEG)			P20 POINTING (DEG)		
CASE	P	Y	R	γ	ρ	σ
6	303.7	0.0	233.2	-28.1	19.4	228.0
6A	0.0	90.0	187.0	270.0	83.0	270.0
6B	123.7	340.0	53.3	218.2	5.9	-44.6

The gravity gradient torques experienced in these three attitudes are presented in Figures 21 through 23. Except for Case 6 (Figure 21), the torques prevail primarily in one axis. In Case 6A, the torque is mainly about the Y axis but is bi-directional since the vehicle X axis will be limit cycling through the local vertical plane. As a result, the Y axis attitude error will be limit cycling (see Figure 24). For Case 6B, the torque is primarily about the Z axis and is uni-directional so the vehicle will seek one side of the Z attitude deadband (see Figure 25).

For Case 6, the torque is about Y and Z causing the vehicle to seek one side of both the Y and Z deadbands (see Figure 26 and 27). As a result, the attitude errors end up in a corner of the combined pitch and yaw control zones (see Figure 28). This results in the vehicle cycling over a smaller portion of the control zone than with a single axis limit cycle and causes an increase in thruster activity.

For the three cases simulated, thruster firings and the orbit fuel usage are summarized below:

CASE	THRUSTER ACTIVITY/ORBIT	FUEL USAGE/ORBIT LB
6	82	0.6
6A	63	0.45
6B	58	0.4

For Cases 6A and 6B, the fuel usage for 9 orbits of doppler tracking can be reasonably extrapolated from the one orbit data. For Case 6, however, the fuel usage will probably continue to increase as the attitude errors move tighter into the corner of the P and Y control zone and as such would be somewhat higher than a linearly extrapolated value from the one orbit data.

"Conclusion"

The Case 6A and 6B attitudes appear to provide the most optimum configuration from a fuel consumption standpoint. The P20 Option 5 mode in conjunction with the CSM DAP provide acceptable control for the CSM doppler tracking experiment.

Figure 21. Case 6 - Gravity Gradient Torques

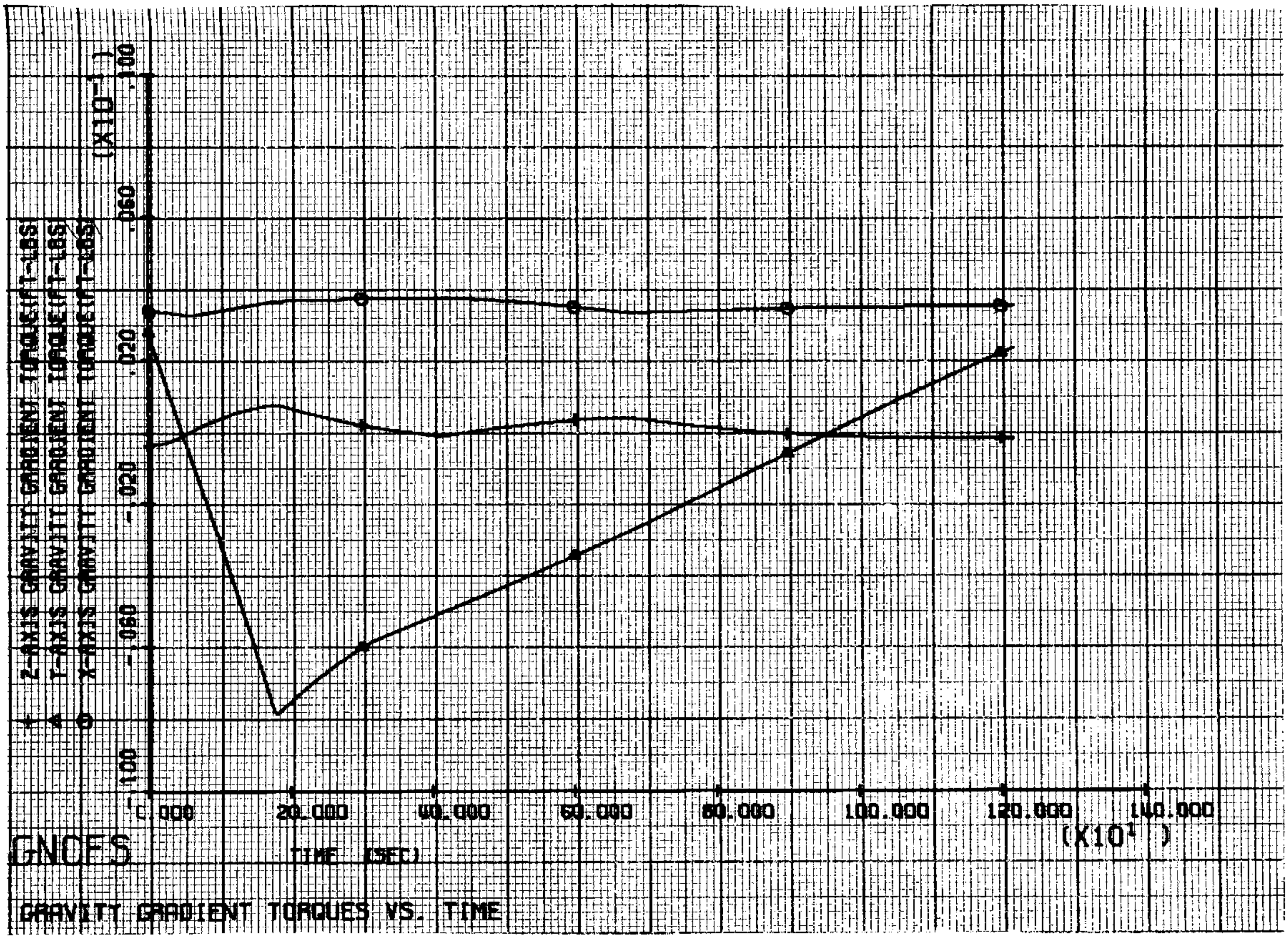


Figure 22. Case 6A - Gravity Gradient Torques

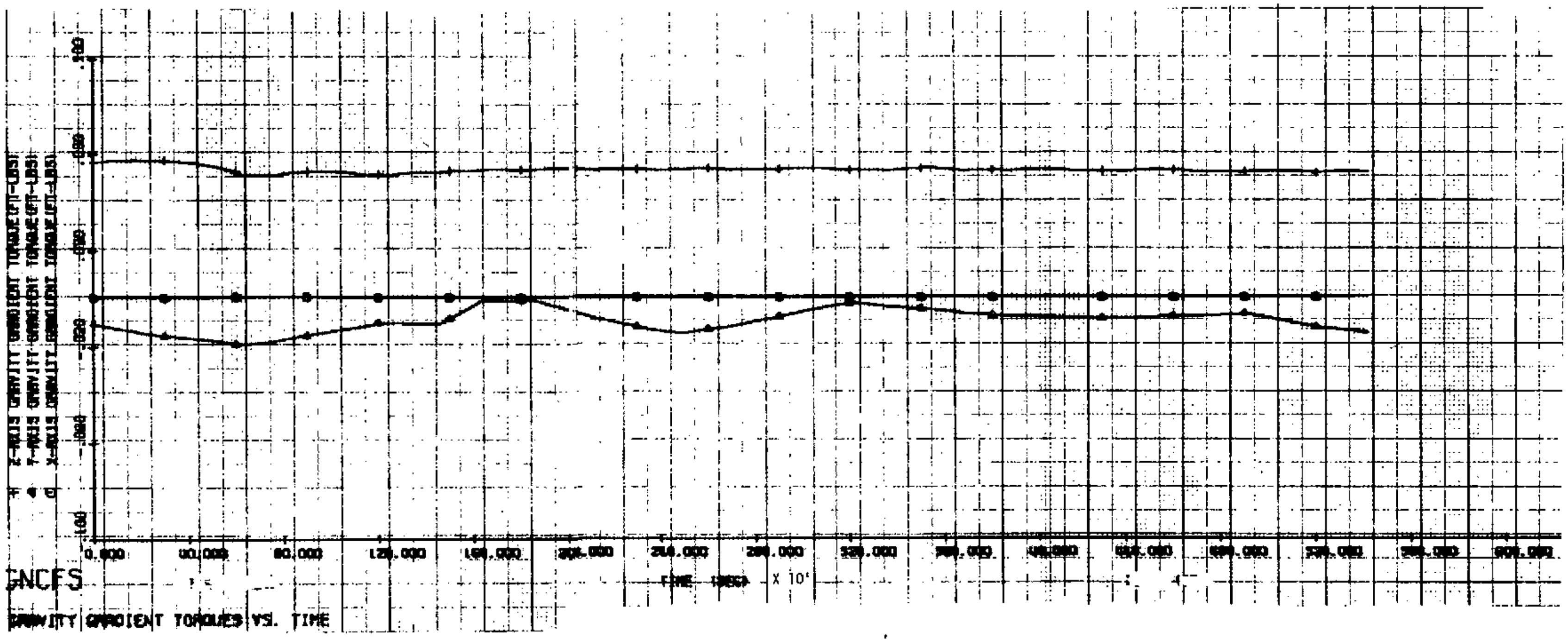


Figure 23. Case 6B - Gravity Gradient Torques

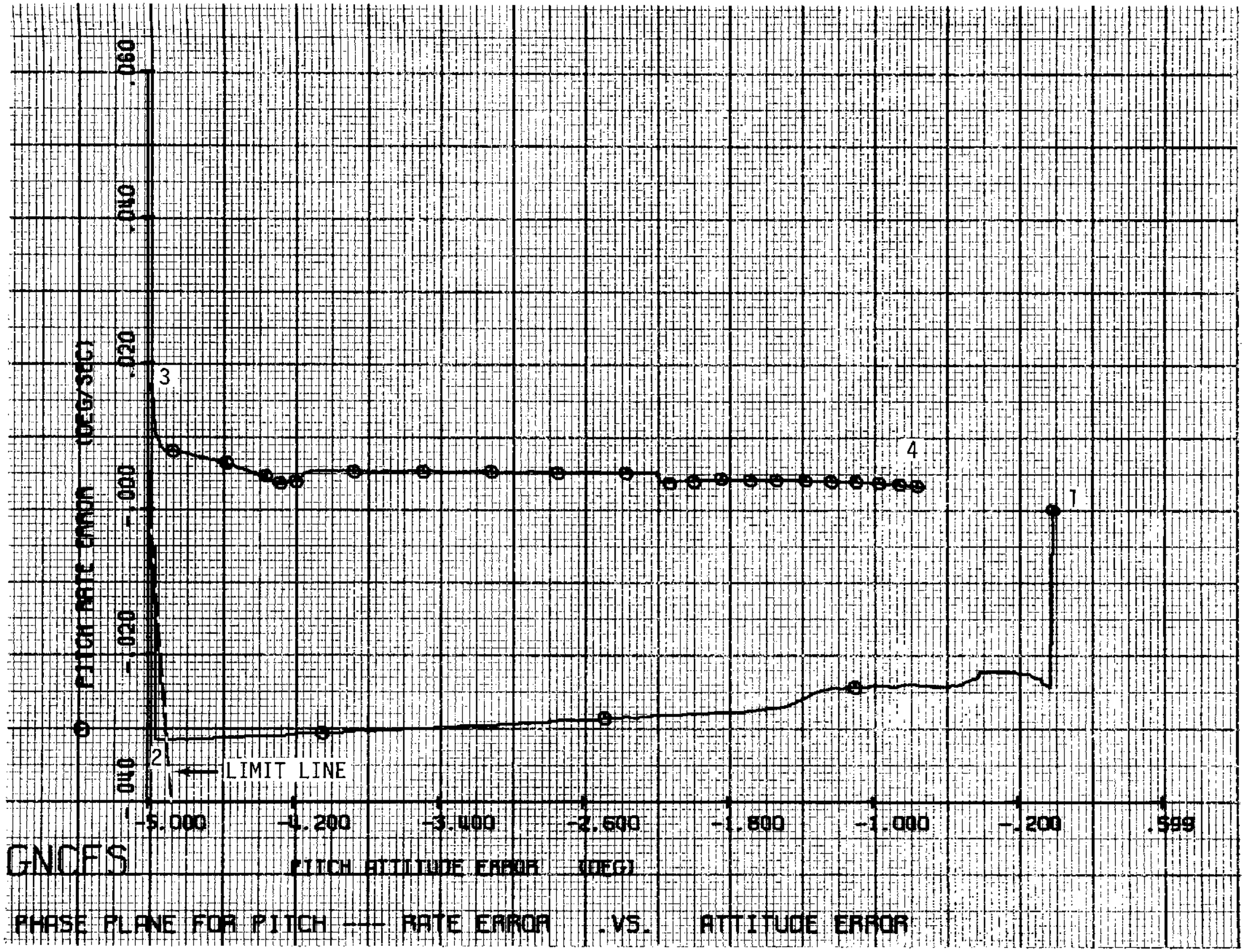


Figure 24. Case 6A - Gravity Gradient Effects on Pitch Phase Plane

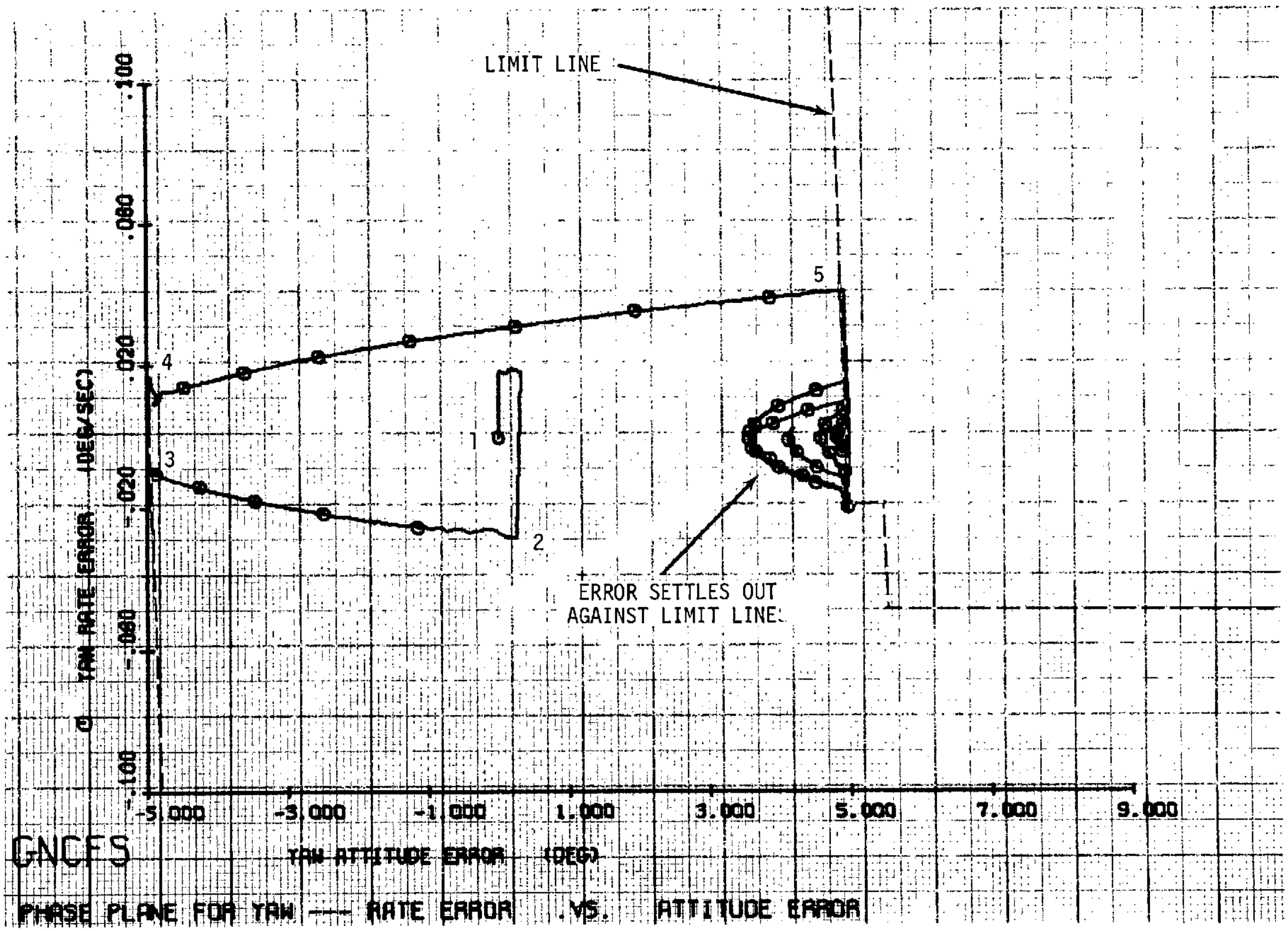


Figure 25. Case 6B - Gravity Gradient Effects on Yaw Phase Plane

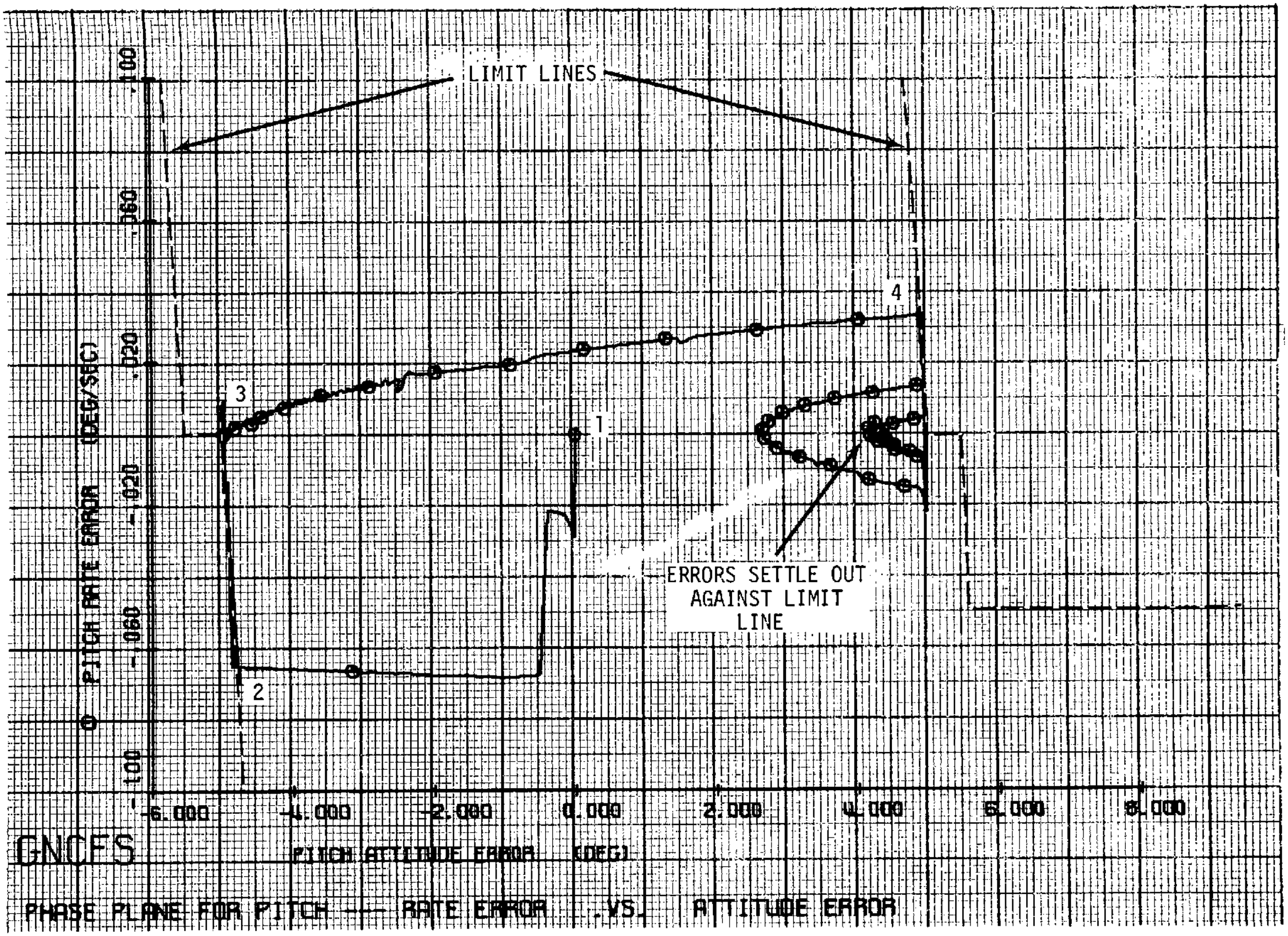


Figure 26. Case 6 - Gravity Gradient Effects on Pitch Phase Plane

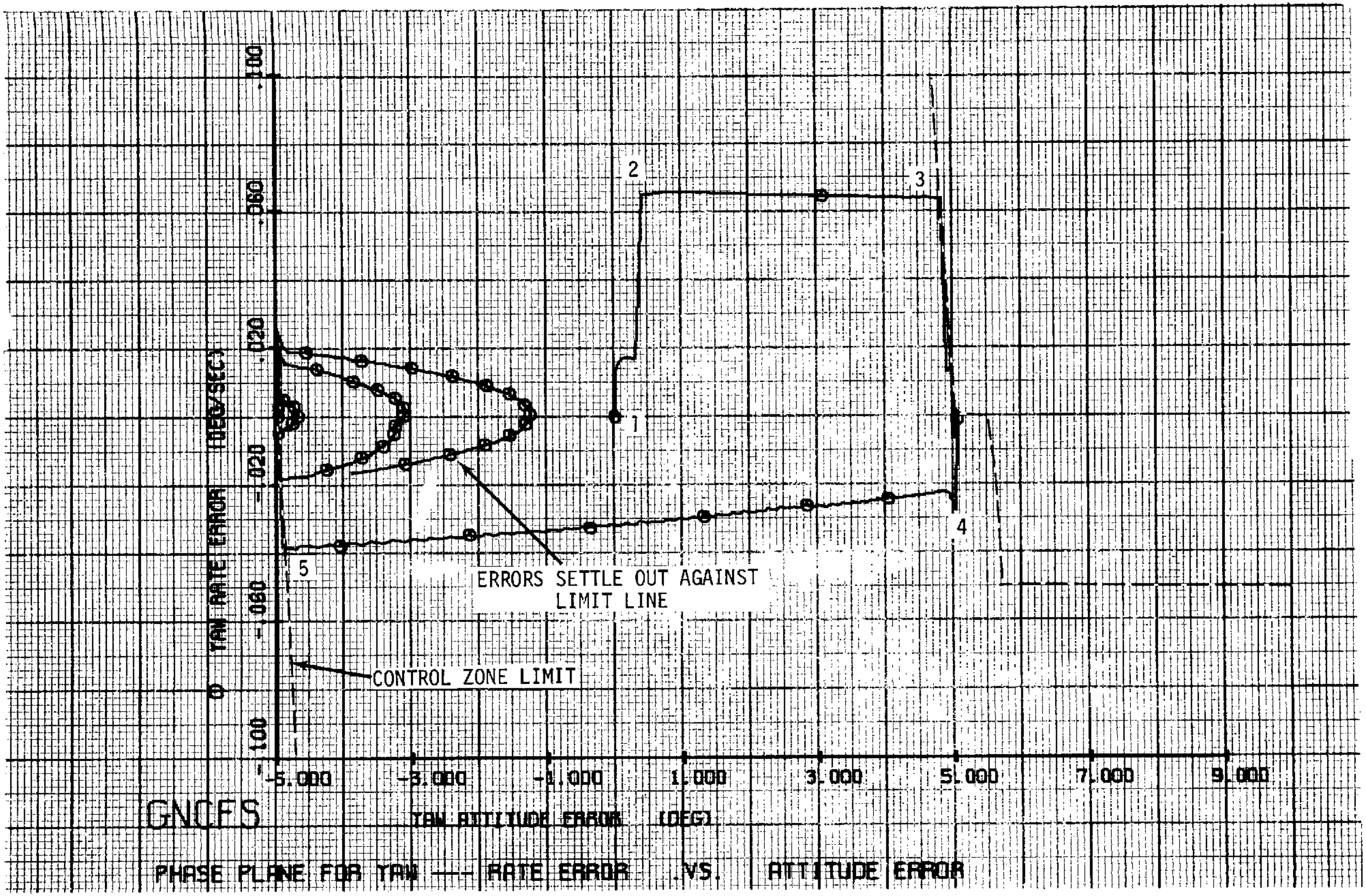


Figure 27. Case 6 - Gravity Gradient Effects on Yaw Phase Plane

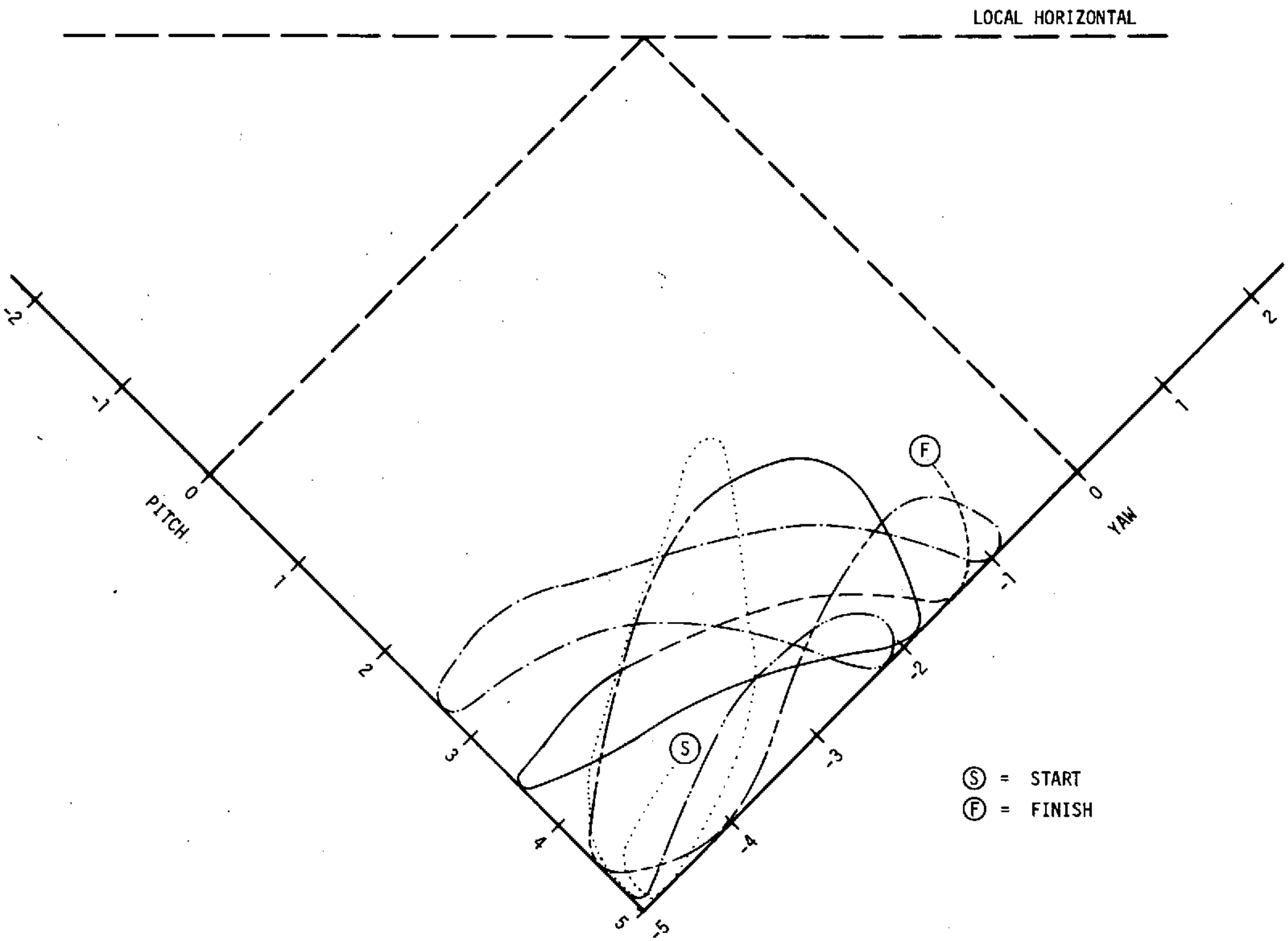


Figure 28. Case 6 - Combined Pitch and Yaw Attitude Errors

ANALYSIS OF CASE 7

"Objective"

To evaluate the capbility to perform a separation maneuver (1 meter/sec) from the Soyuz, in support of Experiment MA148, along an inertial line-of-sight in the presence of small initial attitude rates and in the presence of unbalance torques resulting from c.g. offset when performing a 4 jet X axis RCS translation.

"Test Sequence"

The simulation was initialized with the CSM approximately in plane and the -X axis pointed at the sun. A small residual rate (0.02°/sec) was set into each spacecraft axis simulating the limit cycle rates anticipated before the undocking sequence begins. The control system was configured for CSM DAP, 0.5 degree deadband, and with the roll jets inhibited. Flight planning calls for SCS control with 0.2 degree deadband but SCS capability does not exist on the GNCFS simulator. However, the control configurations are similar enough that some information can be obtained from this simulation. In addition, it was assumed that the Soyuz spacecraft remained inertially fixed during the separation sequence and no docking mechanism torques were applied to the CSM during undocking. So, although the simulation considered a control system with a slightly larger attitude error deadband than the planned control, this difference will most likely be insignificant in comparison to the various other effects not simulated which will be present during the actual separation and will contribute to the separation attitude errors.

The simulation began with a 3 second RCS 4 jet -X translation which yielded 0.45 meter per second of total ΔV. The vehicle developed an average attitude error of 0.17 degree and -0.125 degree in pitch and yaw, respectively during the 3 second thrusting. The vehicle was allowed to coast for 12 seconds and then a 4 second -X translation was applied. This time 0.59 meter/sec of total ΔV resulted. Average attitude errors of 0.58 degree and -0.48 degree in pitch and yaw, respectively, existed during the burn. Figure 29 and 30, phase plane plots for pitch and yaw, show the attitude errors which developed as the result of the unbalanced torques due to c.g. offset. It can be seen that both P and Y errors are up against and in the pitch case even exceed the deadband limits during the second ΔV. The net result of these attitude errors is a CSM separation trajectory which is perturbed from the Soyuz to sun line-of-sight. Based on the attitude errors for both burns, it was computed that the RSS divergence angle from the desired line-of-sight would be approximately 0.6 degree. Figure 31 shows this trajectory error relative to the sun line-of-sight and also shows the angle subtended by the CSM frontal diameter at various separation distances. The final separation rate was 1.04 meter/second, which is slightly more than the desired 1 meter/second. Figure 31 shows one minute time ticks along the trajectory based on the 1 meter/second rate. From Figure 31 it can be seen that the CSM will cease occulting the sun sometime between 2 and 3 minutes.

"Conclusion"

As expected, the pitch and yaw attitude errors rapidly grew during the RCS translational periods and in the pitch case even penetrated the deadband limit. As a result, some significant attitude error resulted during the ΔV period causing a CSM trajectory divergence from the desired path. A similar occurrence can be expected with the CSM SCS control mode. Although the SCS control zone will be slightly tighter, other attitude disturbances plus the Soyuz dynamics will result in considerable difficulty in maintaining the solar eclipse for the desired five minutes.

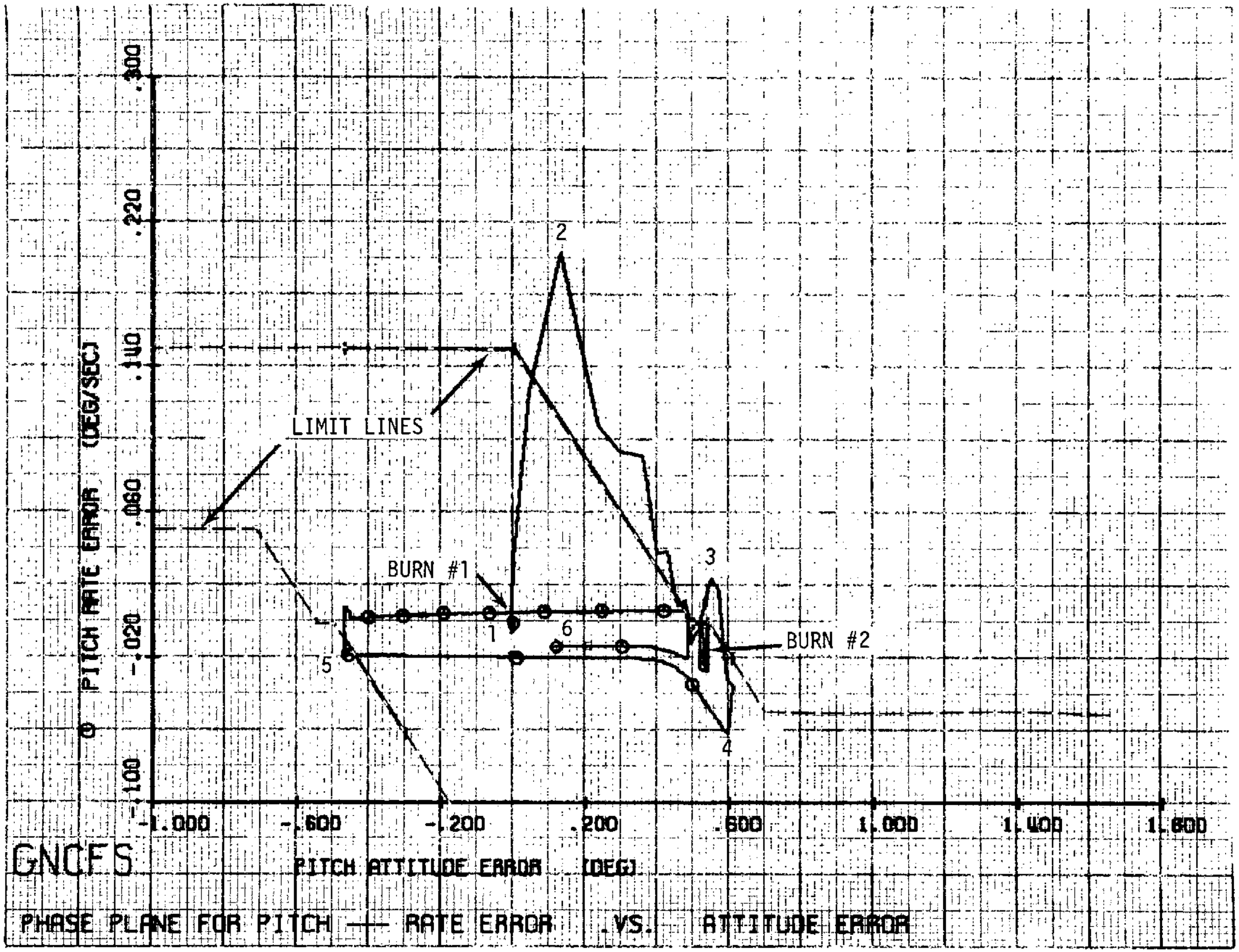


Figure 29. Case 7 - Pitch Axis Phase Plane

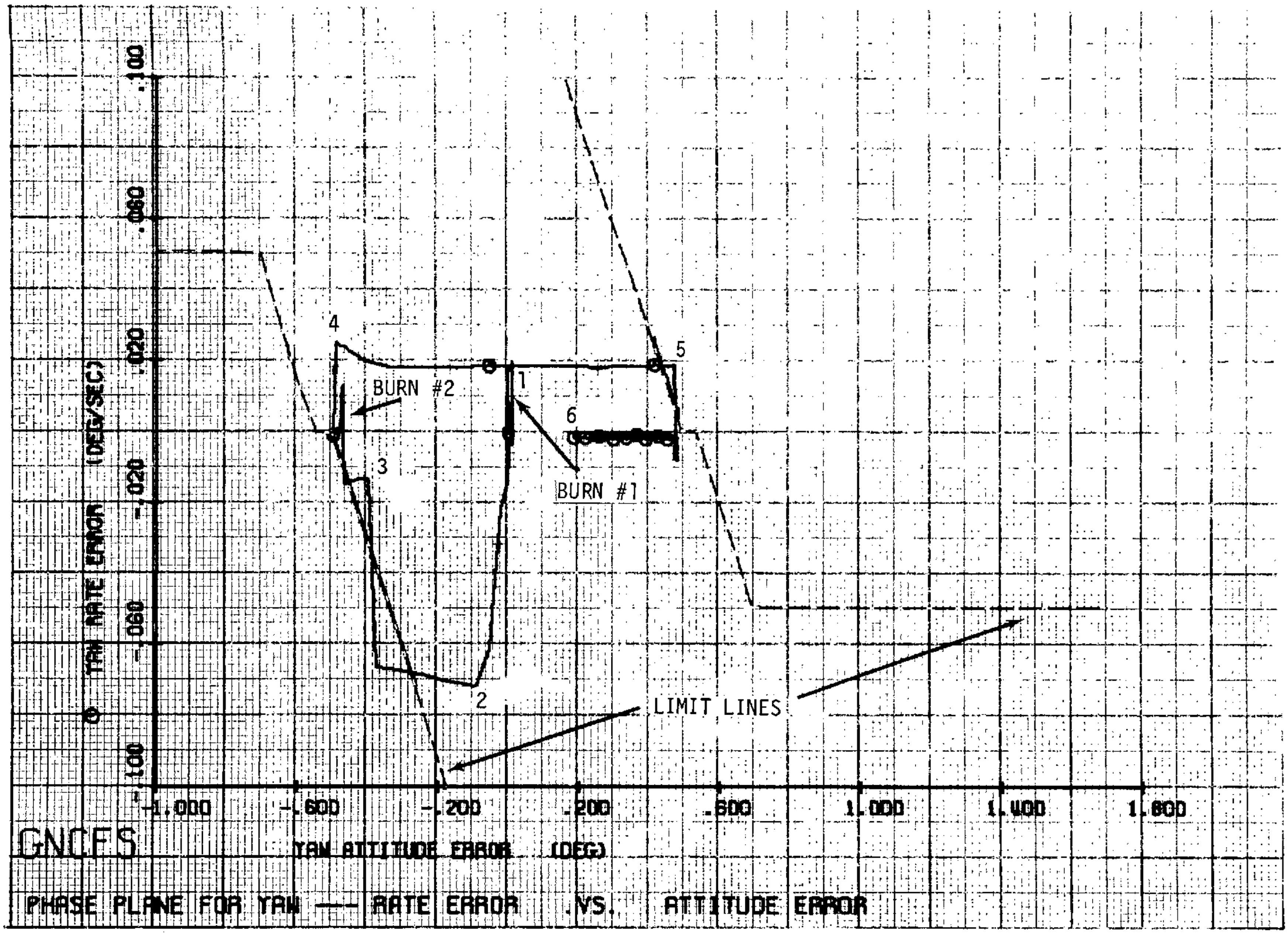


Figure 30. Case 7 - Yaw Axis Phase Plane

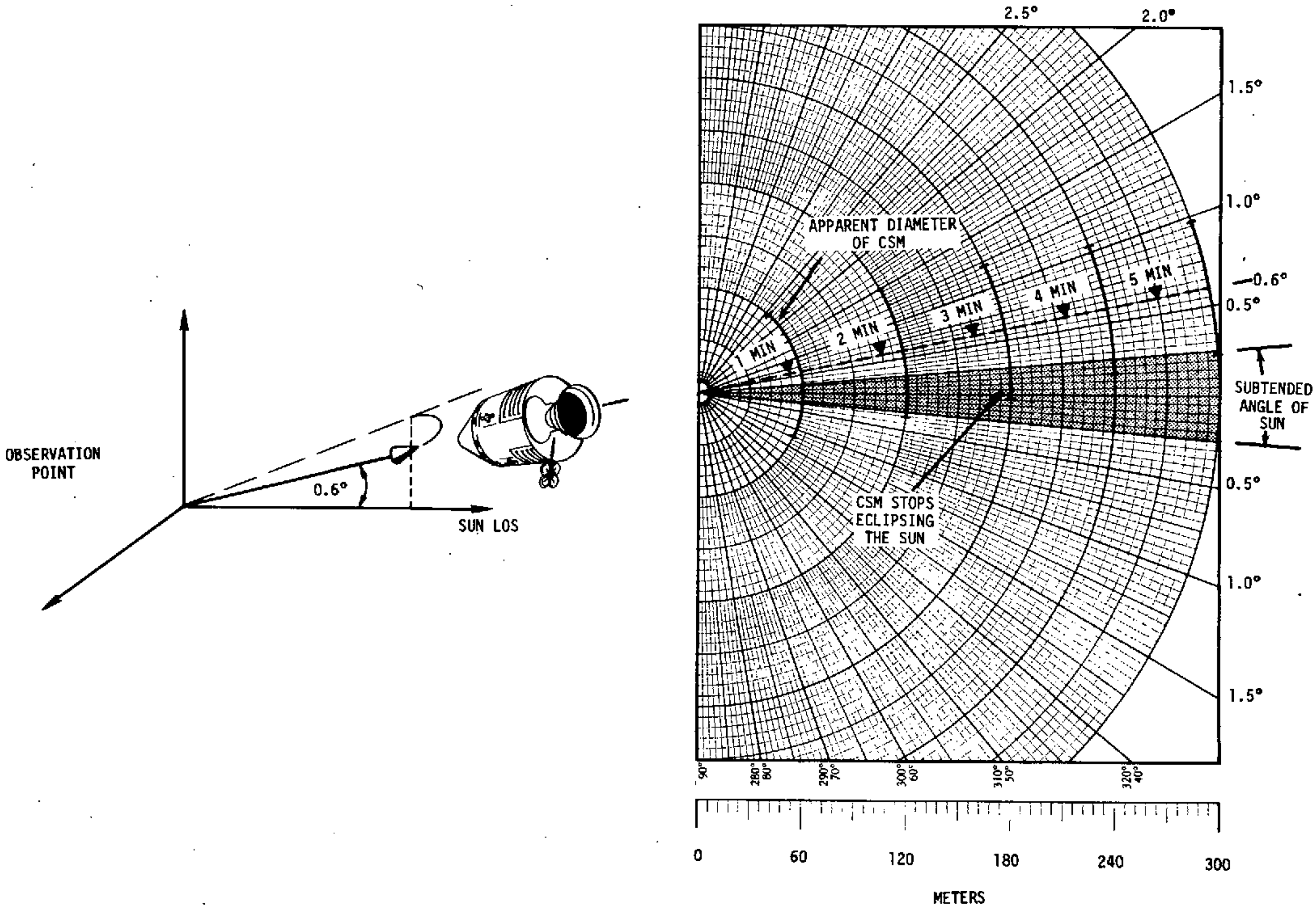


Figure 31. Case 7 - CSM Eclipse of Sun During Separation

REFERENCES

1. "Verification Test Results of Apollo Stabilization and Control Systems During Undocked Operations," TRW Report 25990-H037-RO-00, dated 14 June 1974.

2. "Phase 1 Verification Test Results of Apollo Stabilization and Control Systems During Docked Operations," TRW Report 20029-H187-RO-00, dated 8 June 1973.

3. "Mission Requirements CSM 111/DM2," JSC Document JSC-08819, dated April 5, 1974.

4. "ASTP Preliminary Reference Attitude and Pointing Time Line," JSC IN 74-FM-58, dated 25 July 1974.