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MEMORANDUM REPORT BRL-MR-3707

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**INITIAL YAWSONDE TESTS OF 155MM  
M864 BASE-BURN PROJECTILE**

VURAL OSKAY  
JAMES M. GARNER

NOVEMBER 1988

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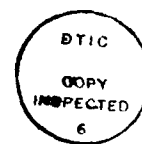
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| 19                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | 06    |                                                    | Flight Dynamics                                                                                      |                                                      |                                  |                            |
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## I. Introduction

Yawsonde tests are normally conducted during the development phase of projectile testing. An initial attempt to conduct the test was made during late 1985 as part of an accuracy test program (sponsored by the Armament Development and Engineering Center (ARDEC)) at Yuma Proving Ground (YPG), Arizona. A single round was tested to impact. However, the projectile did not contain a spotting charge to enhance the probability of locating the impact point. Damp soil conditions from the previous day's rain precluded the observation of impact. Only one test day was allocated for the yawsonde firings; hence, the test program was aborted.

Since then, both the projectile and its base-burn motor grain have gone through modifications to improve system performance. By the time the next yawsonde test series was scheduled, a large volume of firing data existed. Therefore, it was decided that the yawsonde firings would be used to supplement the existing test data. Based upon test conditions specified in Reference 1, twelve(12) M864 projectiles were fired at two QE's with three muzzle velocities. The test matrix is given in Table 1. The purpose of this program was to examine the flight behavior at motor burn-out as a function of velocity and altitude. Since the base-burn motor significantly modifies the base drag, then it could also impact the flight dynamics of the projectile near the motor burn-out. This report presents the results of the yawsonde program.

## II. Test Program and Instrumentation

During the scheduling of this program, several delays were encountered due to various YPG test priorities and hardware delivery difficulties. When the program was finally scheduled, only three days were allocated. One of those three days was used to set up the required instrumentation. As a result, only two days were available to fire the yawsonde program. However, it was decided to reserve one day for contingencies and test all rounds in one day. Therefore, several of the rounds were fired under non-optimal weather conditions, which caused portions of the flight data to be lost for five high quadrant-elevation rounds.

All test projectiles were instrumented with Ballistic Research Laboratory (BRL) constructed fuze-type yawsondes<sup>2</sup>. A yawsonde is an electro-optical device designed to determine the in-flight behavior of an artillery projectile. It is configured to replace a standard artillery fuze. The yawsonde contains two silicon solar cells, a signal conditioning circuit, a transmitter, and a spin-activated power supply. When a silicon cell is exposed to the sunlight, it will generate a DC voltage that is used to modulate a subcarrier oscillator that feeds an RF transmitter. Voltages from both silicon cells are combined to generate an analog signal whose phase is related to the shell's angle with respect to the sun. The transmitted signal is received on the ground and demodulated to remove the carrier frequency. The resulting subcarrier signal is recorded on analog tape for later analysis. The subcarrier

<sup>1</sup>Test Program Request (TPR) (LCU-S-2973) Revision 1 to Amend. 2, Supl. 6 for Projectile, 155mm: Extended Range, DP, XM864 (TECOM Project No. 2-MU-003- 864-003), ARDEC, Dover, New Jersey, 13 May 1987

<sup>2</sup>Mermagen, W. H. and Clay, W. H., "The Design of a Second Generation Yawsonde," MR-2368, U. S. Army Ballistic Research Laboratory, APG, MD, April 1974. (AD 780064)

is discriminated to reproduce the original raw yawsonde pulse train. These pulse data can be related to the Eulerian roll rate,  $\phi$ , which at small yaw angles closely approximates the spin, and the complementary solar angle,  $\sigma_n$ , which yields yaw data through the individual calibration of that yawsonde obtained during its manufacture.<sup>3</sup> The angle,  $\sigma_n$ , is defined as the angle between the normal to the projectile's spin axis and a line to the sun from the projectile's center of mass. The value of  $\sigma_n$  depends on the sun's location (test site, time of the year, time of the day), the line of fire, the trajectory angle, and the local value of the shell's yaw.

The yawsonde data were acquired by Harry Diamond Laboratory (HDL) personnel using their instrumentation van. Two helical antennas were used, and the output of each antenna was fed into a separate P-band receiver through a pre-amplifier. The video signals were then recorded on an analog tape for subsequent analysis. The receiving station was located 500 meters behind the gun and about 15 degrees to the right of line of fire. Muzzle velocities were measured by doppler velocimeters. Two Hawk doppler radars covered the full trajectory. The maximum range of the Hawk is about 15 kilometers. Hence, one radar was placed behind the gun at the test site, while a second radar was located down range to acquire the incoming shell and to track it to impact. However, the second radar did not track any of the rounds. In addition to the Hawk radars, the ARBAT (Applications of Radar to Ballistic Acceptance Testing) radar was used in both a position tracking and a doppler mode. The projectile impact points reported here were determined by four observation stations that were moved to appropriate locations according to the estimated impact points.

### III. Test Results

Results of the test program will be discussed under two headings: real-time observer data and yawsonde reductions. The real-time observer data will give the test conditions, shell related information, muzzle velocities, and impact points. The yawsonde reductions will be plots of  $\sigma_n$  and  $\phi$  as functions of flight time for each test projectile.

#### 1. Real-Time Observer Data

As indicated in Table 1, the test program consisted of two QE's and three muzzle velocities. These conditions were selected to match some of the previous developmental tests. However, the requirements for the yawsonde operations necessitated modification of the firing order from the one shown in Table 1. It was possible to start the low QE tests after 1000 hours whereas, the high QE rounds could not be fired before 1300 hours. Table 2 lists tube round number, projectile type, yawsonde number, muzzle velocity, impact range, and other relevant details for each round in the order of launch. Some of the delays during the test were required so that the observers could be moved to different observation sites, while additional delays were encountered near the end of the firing program when

<sup>3</sup>Clay, W. H., "A Precision Yawsonde Calibration Technique", MR 2263, U. S. Army Ballistic Research Laboratory, APG, MD, January 1973. (AD 758158)

clouds partially obscured the sun. Although the impact data must be corrected for muzzle velocity and meteorological conditions, the preliminary impact data did not indicate any unexpected flight behavior.

## 2. Initial Yawsonde Observations

Initial observations from the yawsonde tests of M864 projectile are listed in Table 3. Changes in line of fire, observer movements, and variations in the weather conditions are especially important and affect the timing and the clarity of the yawsonde data.

## 3. Yawsonde Reductions

The reduced yawsonde data will be discussed in sections 4 and 5. They are presented in terms of "yaw angle" ( $\sigma_n$ ) and "spin rate" ( $\dot{\phi}$ ) in the projectile-sun system. The character of the  $\sigma_n$  data is determined by the yawing motion, the sun's position with respect to the line of fire, and the trajectory of the test item. However, in spite of these complications, the basic features of the yawing behavior are faithfully represented by the  $\sigma_n$  versus time plots. The peak-to-peak excursions of  $\sigma_n$  represent the total angular motion about the trajectory. Since the projectile is traveling on an earth fixed coordinate system rather than a shell fixed system, the "spin" measured by the yawsonde, is the rate of change of the Euler angle of the shell. Therefore, under conditions of large yaw, the plot of  $\dot{\phi}$  versus time will show modulations which are not really spin variations.<sup>4</sup> However, the average of these oscillations closely approximates the actual spin history of the shell along its trajectory.

## 4. Yaw Angle Versus Time

Plots of  $\sigma_n$  versus time for the M864 shell are presented in Figures 1 through 12. Rounds 4258 and 4259 were fired with M119A2 propellant at a QE of 355 mils (20 degrees) and had live base-burn units. Both projectiles showed very small initial yaws which quickly damped (see Figures 1 and 2a). At the beginning of Figure 2a, there seemed to be a change in the yaw level; a close scrutiny of that region (Figure 2b) indicated that the observed level change was due to signal irregularity and not a change in the yawing behavior of the shell. Note that on both sides of the step, the same yaw level was visible. However, the data from both rounds gave indications of RF interference between 25 and 30 seconds, where the base-burn grain is near extinguishment. The source of the poor signal to noise ratio is unknown.

One of the three projectiles fired with the M203A1 charge at a QE of 355 mils had an inert base-burn unit. Both of the live base projectiles showed about 2 degrees of yaw early in their flight; but this yaw quickly damped (see Figures 3 and 4a). These flight data also exhibited noise in the region of 30 to 35 seconds into the flight. Finally, they gave an

<sup>4</sup>Murphy, C. H., "Effects of Large High-Frequency Angular Motion of a Shell on the Analysis of Its Yawsonde Records", ARBRL-MR-2581, U. S. Army Ballistic Research Laboratory, APC, MD, February 1976. (AD 0094210)

indication of a small slow-mode limit cycle near impact. The early part of Figure 4a showed some sizeable motion. Again, after closer scrutiny (see Figure 4b), it was obvious that the apparent motion was really noise in the reduced data due to signal form irregularities. The yawing motion of the inert base-burn round (Round 4262) is plotted in Figure 5. Very little motion was evident early in the flight, but some indication of a slow mode limit cycle was seen near impact. Again, there was signal noise in the time frame between 20 and 35 seconds, indicating that under this flight condition the receiving antenna was probably looking at the null of the transmitting antenna.

The next seven rounds were fired at QE of 1150 mils (64.5 degrees). Their yawing behaviors are shown in Figures 6 through 12. The first three rounds (Figures 6, 7, and 8) were fired with the M203A1 charge. Rounds 4271 and 4272 had live base-burn motors, while Round 4273 had an inert one. Figure 6, Round 4271, showed a small amplitude yawing motion that was dominated by the slow precessional mode. This motion was damped by 25 seconds, however. Unfortunately, due to poor sun conditions, there were no comparable early data for the next two flights (Figures 7 and 8). Rounds 4274 and 4275 were fired with M119A2 charge. They both had live base-burn motors. As before, the data in Figure 9 (Round 4274) showed a small amplitude, slow precessional mode motion early in the flight. The shift in the mean yaw level was produced by the effects of background sunlight conditions on the video signal quality. Although there were no early data for the yawing behavior of Round 4275, Figure 10 does not provide any reason to believe that the behavior was different from that of the previous round. The final two rounds were fired with M4A2 Zone 7 charge (one live and one inert base-burn unit). Data are shown in Figures 11 and 12 and do not indicate any unexpected behavior. The larger amplitude slow precessional mode motion of Round 4277 (around 20 seconds) could be due to the wind effects rather than any major aerodynamic difference between the inert and live rounds.

## 5. Roll Rate Versus Time

Plots of  $\dot{\phi}$  are given in Figures 13 through 24 as a function of flight time. Some of the  $\dot{\phi}$  data (Figures 17, 19, 20, 22, 23, and 24) were not obtained from the yawsonde pulse data due to signal distortions. Hazy sky conditions produce two undesirable effects: (1) pulse shapes that do not have sharp leading edges and (2) baseline voltages (the signal level away from base of the pulses) that are non-zero. However, the basic pulse ensemble (a group of three pulses, positive, negative, and positive) and the associated baseline still contain information from which the roll period can be extracted. The raw analog yawsonde voltage can, therefore, be processed by a spectrum analyzer (SA) to extract the roll period. The resolution and data density of SA-obtained roll data are far less than those of a standard yawsonde reduction. The SA data are digitally filtered, but residual perturbations are still present. These perturbations are an artifact of the SA method and do not reflect unusual roll behavior by the projectile.

Figures 13 and 14 show the spin histories of the two live rounds fired with M119A2 charge at a QE of 355 mils (20 degrees). A comparison of the data in these figures indicates consistent performance with no unexpected spin behavior near burn-out, which should have occurred at about 30 seconds. Spin data from the projectiles fired with the

M203A1 charge are shown in Figures 15, 16, and 17. Rounds 4260 and 4261 also showed consistent behavior with no undue spin changes near burn-out. Round 4262 had an inert motor and also showed a normal spin decay.

Figures 18 through 24 show the spin histories of the M864 projectiles fired at a QE of 1150 mils (64.5 degrees). Data in Figures 18 and 21 were obtained from the yaw reduction and, thus, terminate at about 50 seconds when the trajectory parameters and sunlight conditions limit the yaw data. Figures 18 and 19 give  $\dot{\phi}$  as a function of time for the two live rounds fired with the M203A1 charge. Figure 19 only provides data beyond 35 seconds since the raw signals were very poor and even the SA process returned valid data beyond that time. The spin data for the inert M864 shell fired with the M203A1 charge are shown in Figure 20. There were no spin anomalies for this round. Spin histories for the two live-motor projectiles fired with M119A2 charge are shown in Figures 21 and 22. The data were consistent with no unexpected behavior. Finally, Figures 23 and 24 show the spin histories of the two projectiles fired with the M4A2 Zone 7 charge. The spin histories of the live and inert projectiles were very similar with the exception of a variation on the down leg of their trajectories due to different velocity histories of the shell.

#### IV. Conclusions

Yawsonde and impact data were presented and discussed for supersonic launch conditions. These data do not indicate any unexpected behavior nor do they show any difference in aeroballistic behavior between live and inert base-burn shell. Although increased RF noise was observed between 25 and 30 seconds for most of the projectiles, there were no observable changes in the dynamic behavior of the live-motor projectile in the region of burn-out. During this test series, projectiles were only fired at the three top zones where the flight performance of the shell is typically adequate. No transonic/induced-yaw launch conditions were tested. On the other hand, if other cargo or payload concepts are to be utilized (such as liquid or potentially loose internal parts payloads), then more complete tests should be conducted to assure proper flight performance.

**Table 1. M864 Yawsonde Test Matrix, May 1987**

| Propelling Charge | Base Burn Grain | Quantity Fired | Quadrant Elevation (mils) | Velocity (M/SEC) |
|-------------------|-----------------|----------------|---------------------------|------------------|
| M203A1            | Live            | 2              | 1150                      | 805              |
| M203A1            | Inert           | 1              | 1150                      | 805              |
| M203A1            | Live            | 2              | 355                       | 805              |
| M203A1            | Inert           | 1              | 355                       | 805              |
| M119A2            | Live            | 2              | 1150                      | 675              |
| M119A2            | Live            | 2              | 355                       | 675              |
| M4A2(Z7)          | Live            | 1              | 1150                      | 550              |
| M4A2(Z7)          | Inert           | 1              | 1150                      | 550              |

**Table 2. Round-by-Round Data for M864 Yawsonde Test Firings**

| ROUND NO | BASE BURN | SHELL NO | YAWSONDE NO | CHARGE   | QE (MILS) | TIME OF FIRE(MST) | MUZZLE VEL(M/S) | RANGE (M) |
|----------|-----------|----------|-------------|----------|-----------|-------------------|-----------------|-----------|
| 4258     | LIVE      | Y- 5     | 2242        | M119A2   | 355       | 1008              | 675.7           | 16718     |
| 4259     | LIVE      | Y- 6     | 2243        | M119A2   | 355       | 1014              | 679.4           | 16716     |
| 4260     | LIVE      | Y-11     | 2244        | M203A1   | 355       | 1052              | 807.6           | 21138     |
| 4261     | LIVE      | Y-12     | 2245        | M203A1   | 355       | 1058              | 805.4           | 21109     |
| 4262     | INERT     | Y- 3     | 2246        | M203A1   | 355       | 1103              | 802.6           | 18290     |
| 4271     | LIVE      | Y- 9     | 2247        | M203A1   | 1150      | 1304              | 803.4           | 24590     |
| 4272     | LIVE      | Y-10     | 2248        | M203A1   | 1150      | 1312              | 804.4           | 24838     |
| 4273     | INERT     | Y- 2     | 2249        | M203A1   | 1150      | 1347              | 804.7           | 20160     |
| 4274     | LIVE      | Y- 7     | 2250        | M119A2   | 1150      | 1407              | 676.9           | 18669     |
| 4275     | LIVE      | Y- 8     | 2251        | M119A2   | 1150      | 1425              | 673.1           | 18565     |
| 4276     | LIVE      | Y- 4     | 2252        | M4A2(Z7) | 1150      | 1448              | 552.4           | 14196     |
| 4277     | INERT     | Y- 1     | 2253        | M4A2(Z7) | 1150      | 1457              | 547.9           | 12080     |

**Table 3. Preliminary Observations During Yawsonde Firings of M864**

| ROUND NO | YAWSONDE NO | QE (MILS) | AZIMUTH FROM NORTH (DEG:MIN) | TIME OF FIRE (MST) | REMARKS                                                                                                       |
|----------|-------------|-----------|------------------------------|--------------------|---------------------------------------------------------------------------------------------------------------|
| 4258     | 2242        | 355       | 75:50                        | 1008               | Clean signal to impact                                                                                        |
| 4259     | 2243        | 355       | 75:50                        | 1014               | Clean signal to impact                                                                                        |
| 4260     | 2244        | 355       | 75:50                        | 1052               | Moved observers; clean signal to impact                                                                       |
| 4261     | 2245        | 355       | 75:50                        | 1058               | Clean signal to impact                                                                                        |
| 4262     | 2246        | 355       | 75:50                        | 1103               | Clean signal to impact                                                                                        |
| 4271     | 2247        | 1150      | 73:30                        | 1304               | Moved observers; good signal within window                                                                    |
| 4272     | 2248        | 1150      | 73:30                        | 1312               | Partial clouds; some signal modulation at start; good signal within window                                    |
| 4273     | 2249        | 1150      | 73:30                        | 1347               | Moved observers; good signal within window                                                                    |
| 4274     | 2250        | 1150      | 74:00                        | 1407               | 10-minute hold for clouds; good signal within window                                                          |
| 4275     | 2251        | 1150      | 74:00                        | 1425               | 9-minute hold for clouds; good signal within window                                                           |
| 4276     | 2252        | 1150      | 74:00                        | 1448               | 19-minute hold for clouds; moved observers; some signal modulation at start; good signal within window        |
| 4277     | 2253        | 1150      | 74:00                        | 1457               | 5-minute hold for clouds; signal amplitude modulations during the first 10 minutes; good signal within window |

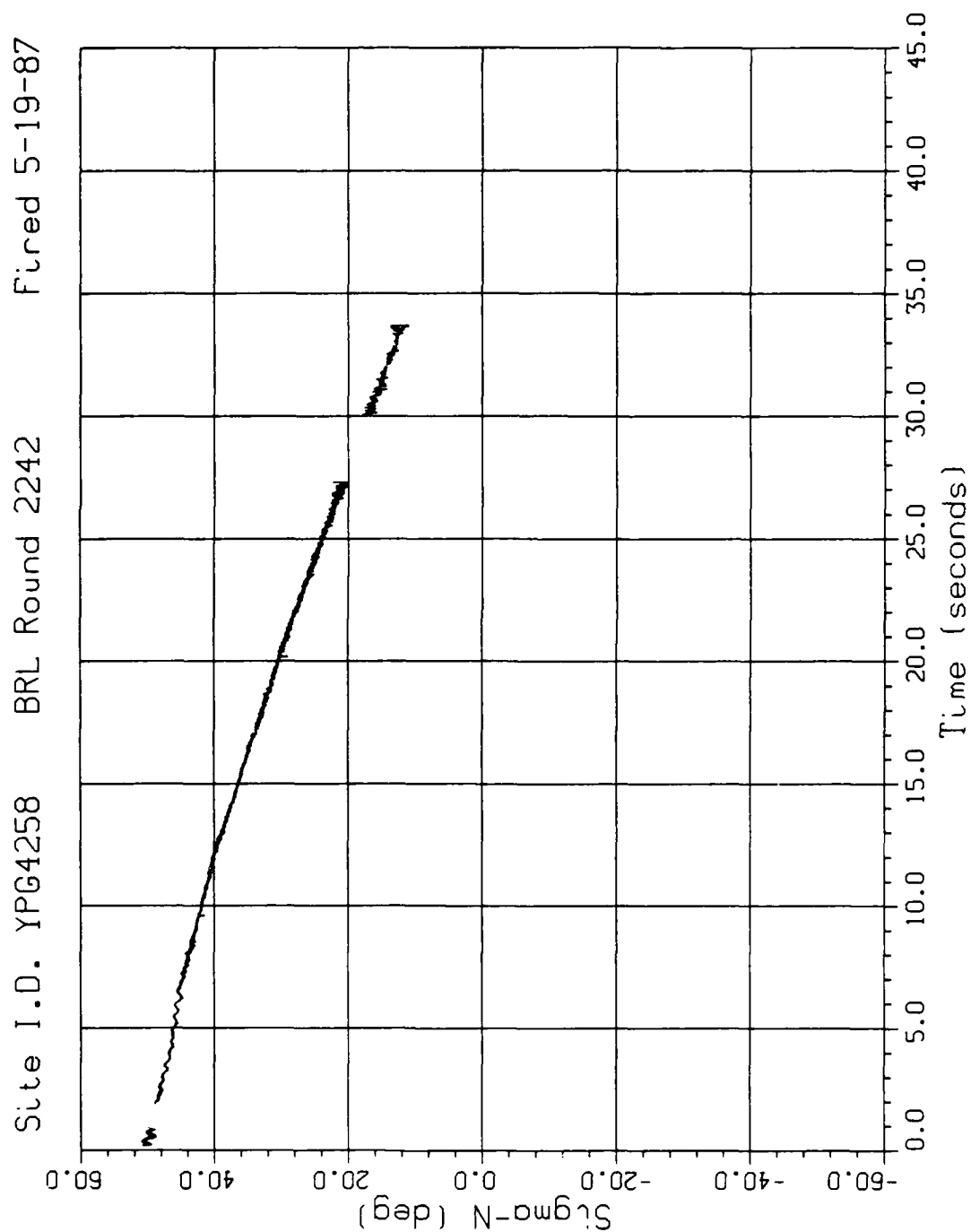


Figure 1. Yaw Angle Versus Time, Round 4258 (Yawsonde 2242)

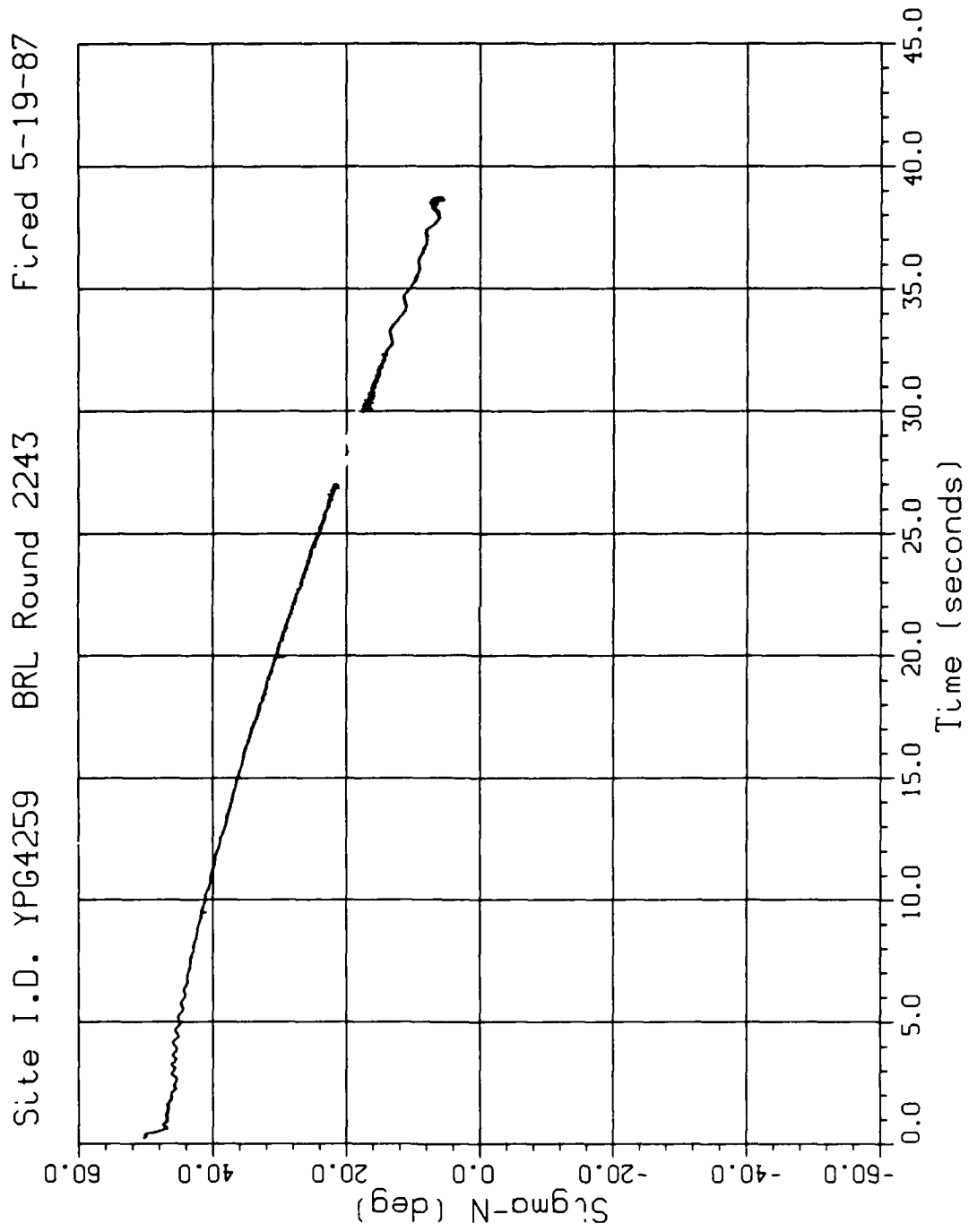


Figure 2a. Yaw Angle Versus Time, Round 4259 (Yawsonde 2243), 0-45 Seconds

Site I.D. YPG4259      BRL Round 2243      Fired 5-19-87

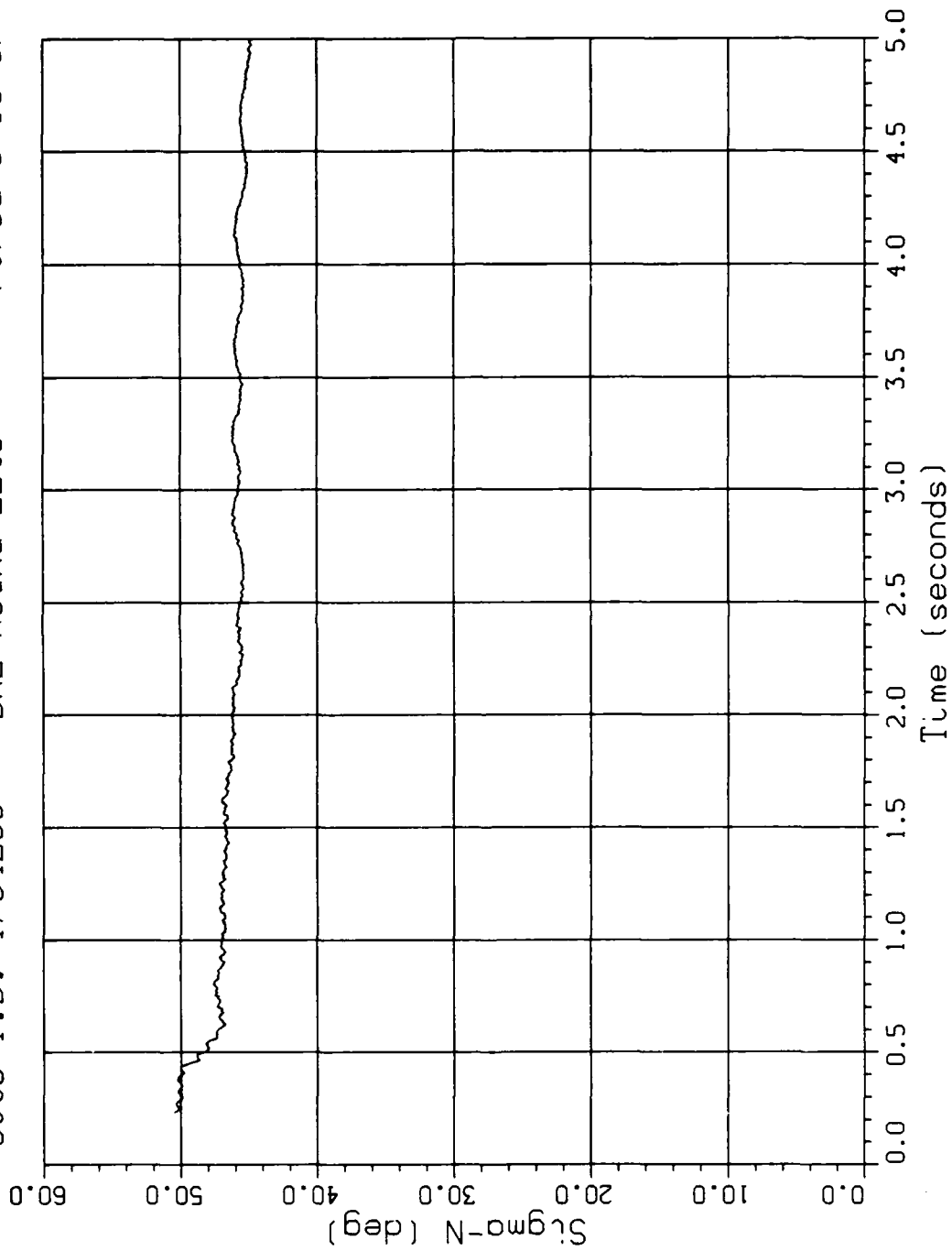


Figure 2b. Yaw Angle Versus Time, Round 4259 (Yawsonde 2243), 0-5 Seconds

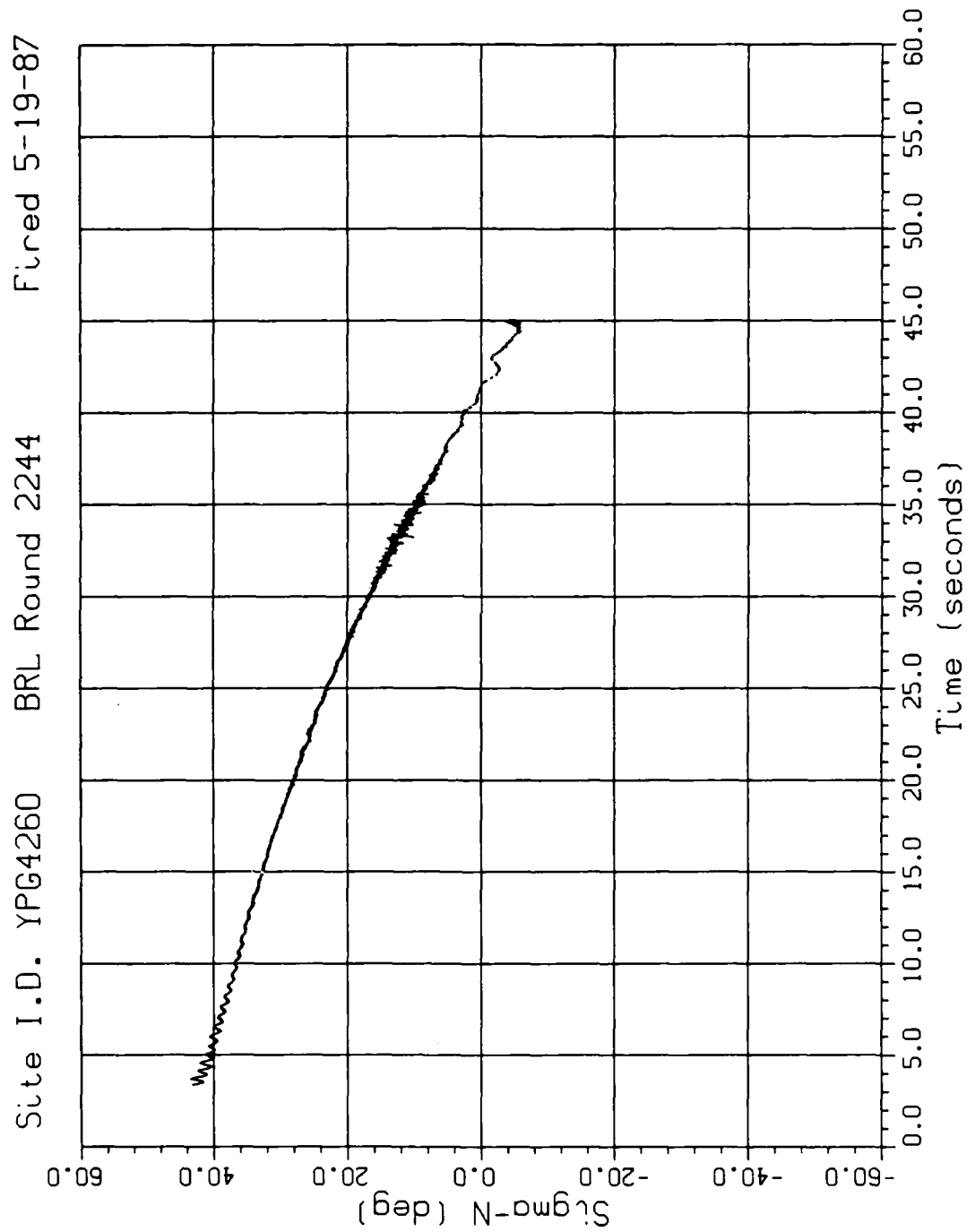


Figure 3. Yaw Angle Versus Time, Round 4260 (Yawsonde 2244)

Site I.D. YPG4261      BRL Round 2245      Fired 5-19-87

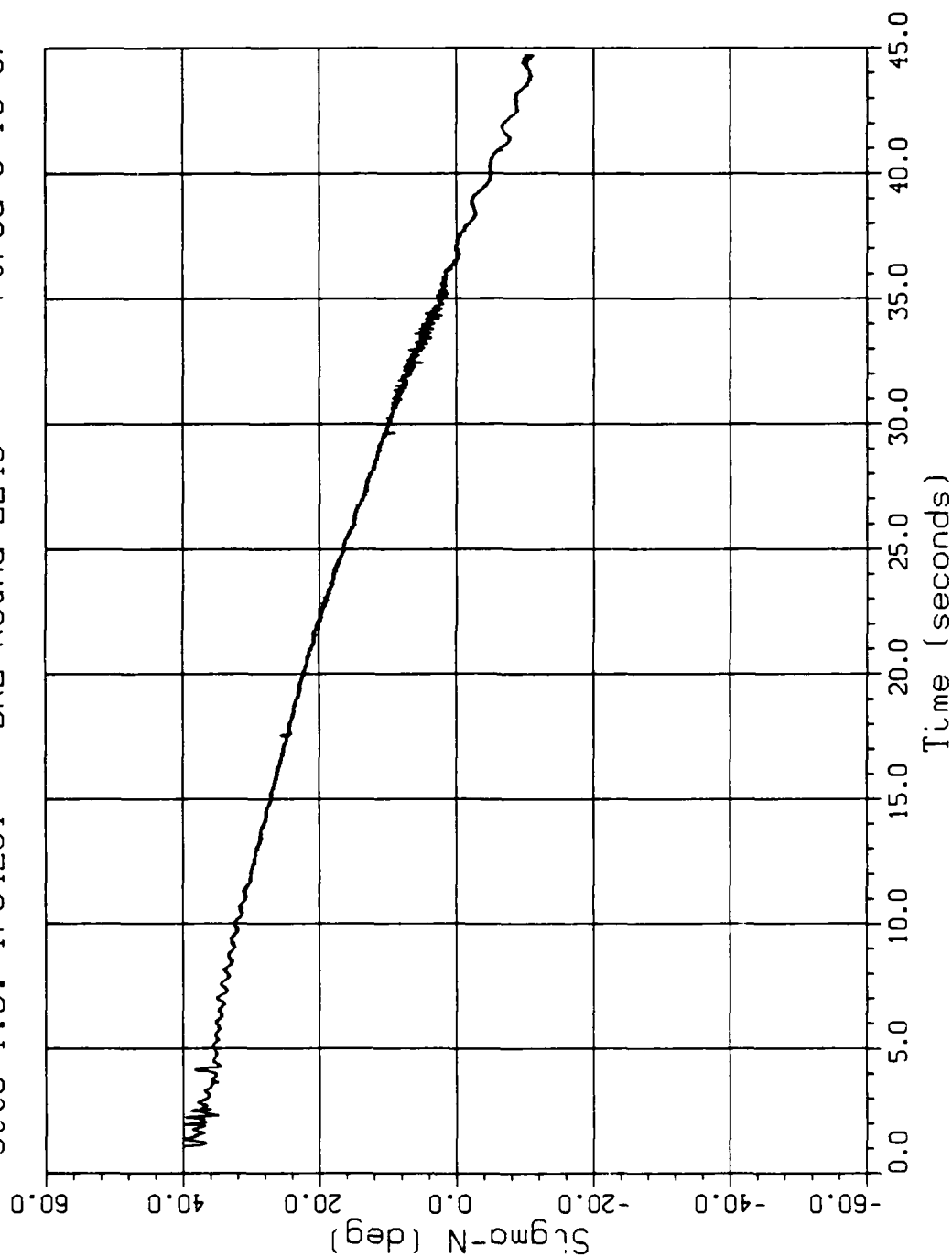


Figure 4a. Yaw Angle Versus Time, Round 4261 (Yawsonde 2245), 0-45 Seconds

Site I.D. YPG4261      BRL Round 2245      Fired 5-19-87

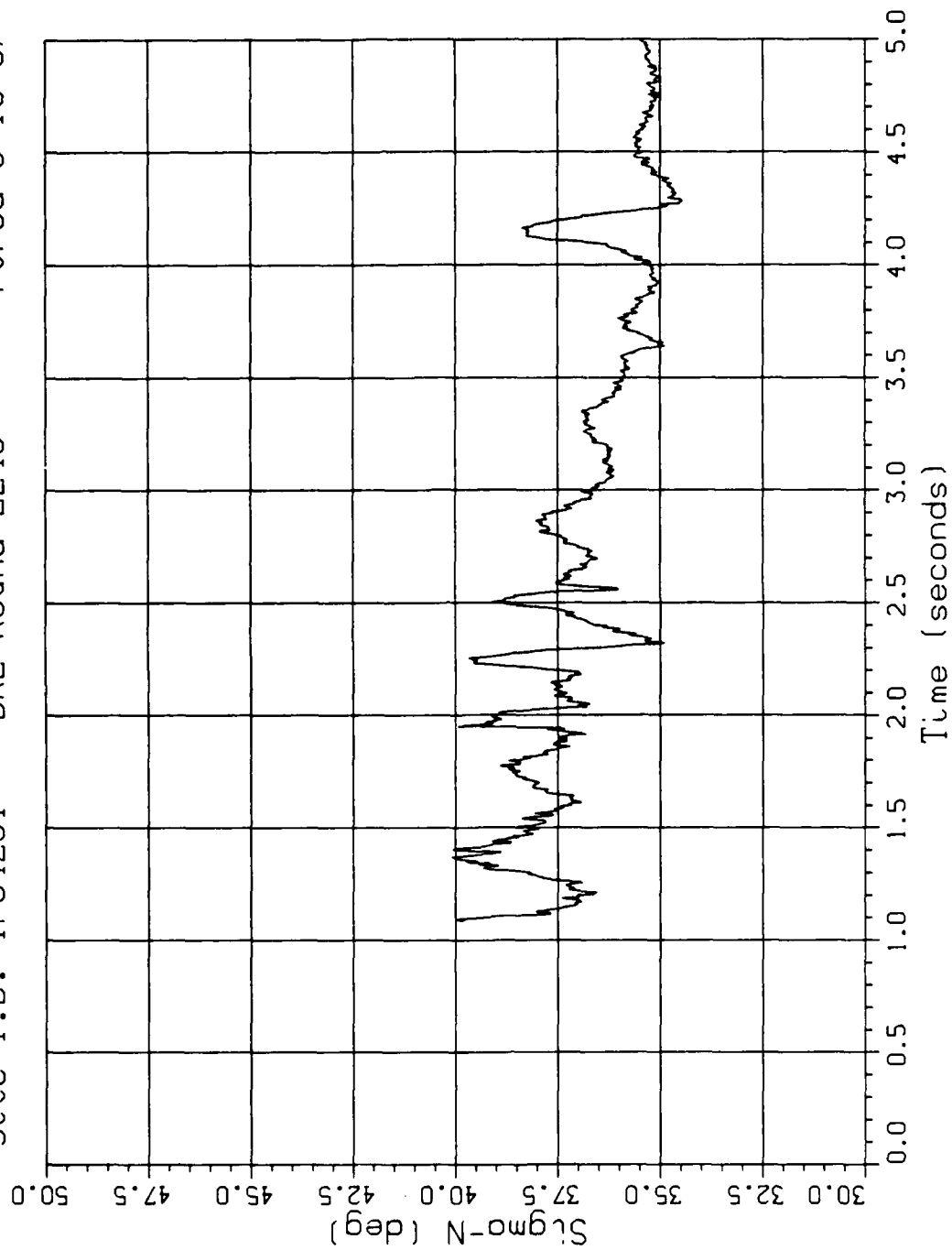


Figure 4b. Yaw Angle Versus Time, Round 4261 (Yawsonde 2245), 0-5 Seconds

Site I.D. YPG4262      BRL Round 2246      Fired 5-19-87

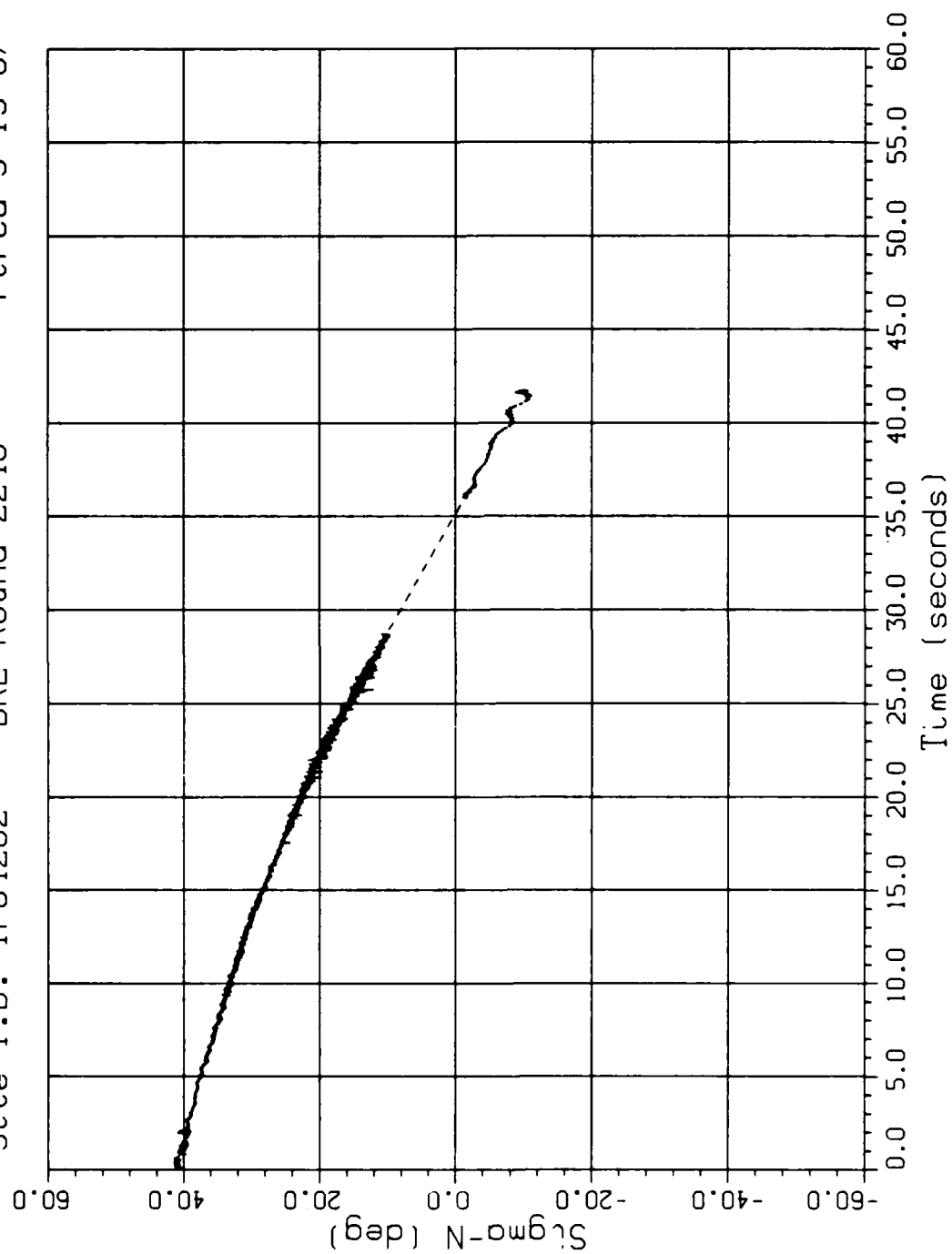


Figure 5. Yaw Angle Versus Time, Round 4262 (Yawsonde 2246)

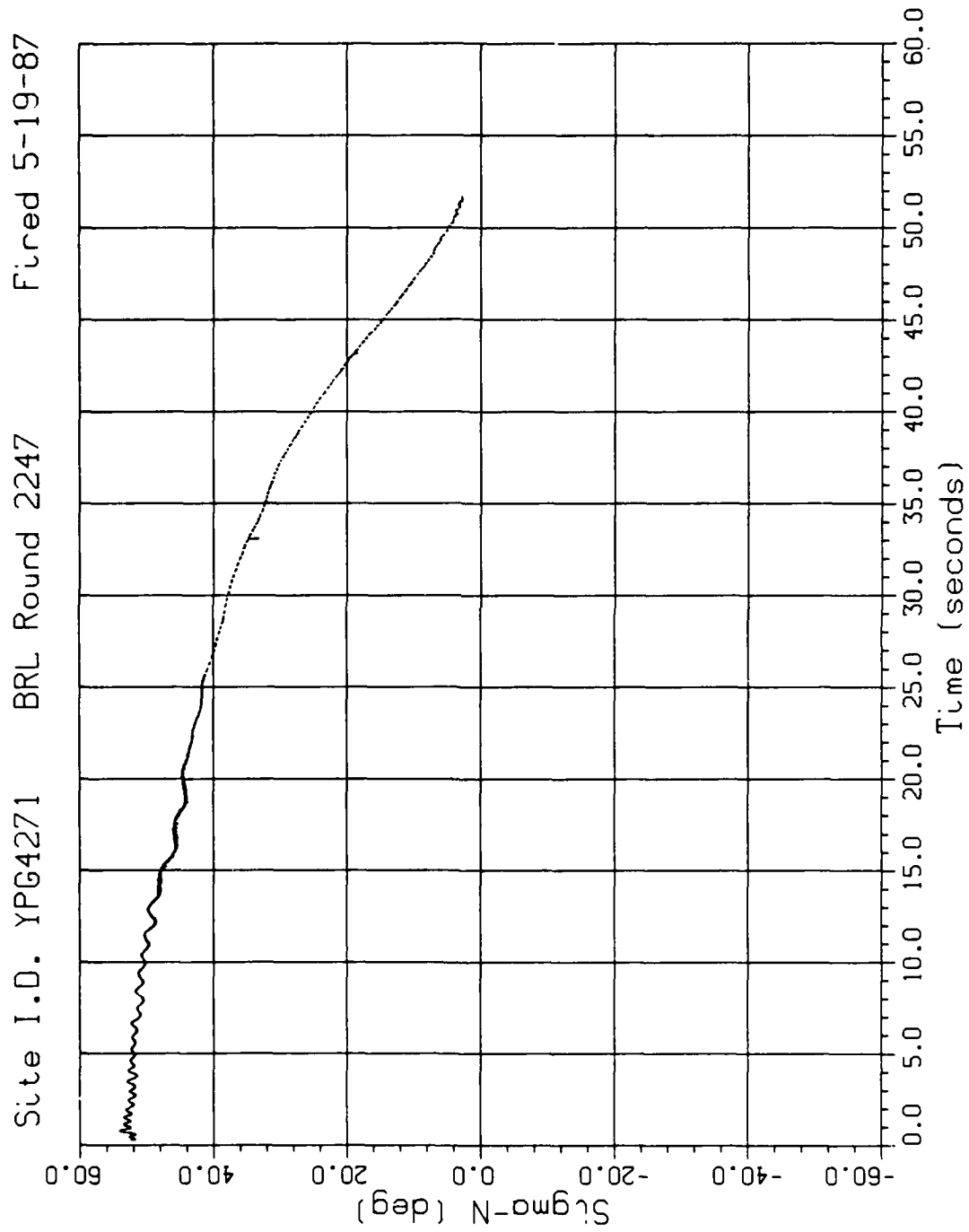


Figure 6. Yaw Angle Versus Time, Round 4271 (Yawsonde 2247)

Site I.D. YPG4272      BRL Round 2248      Fired 5-19-87

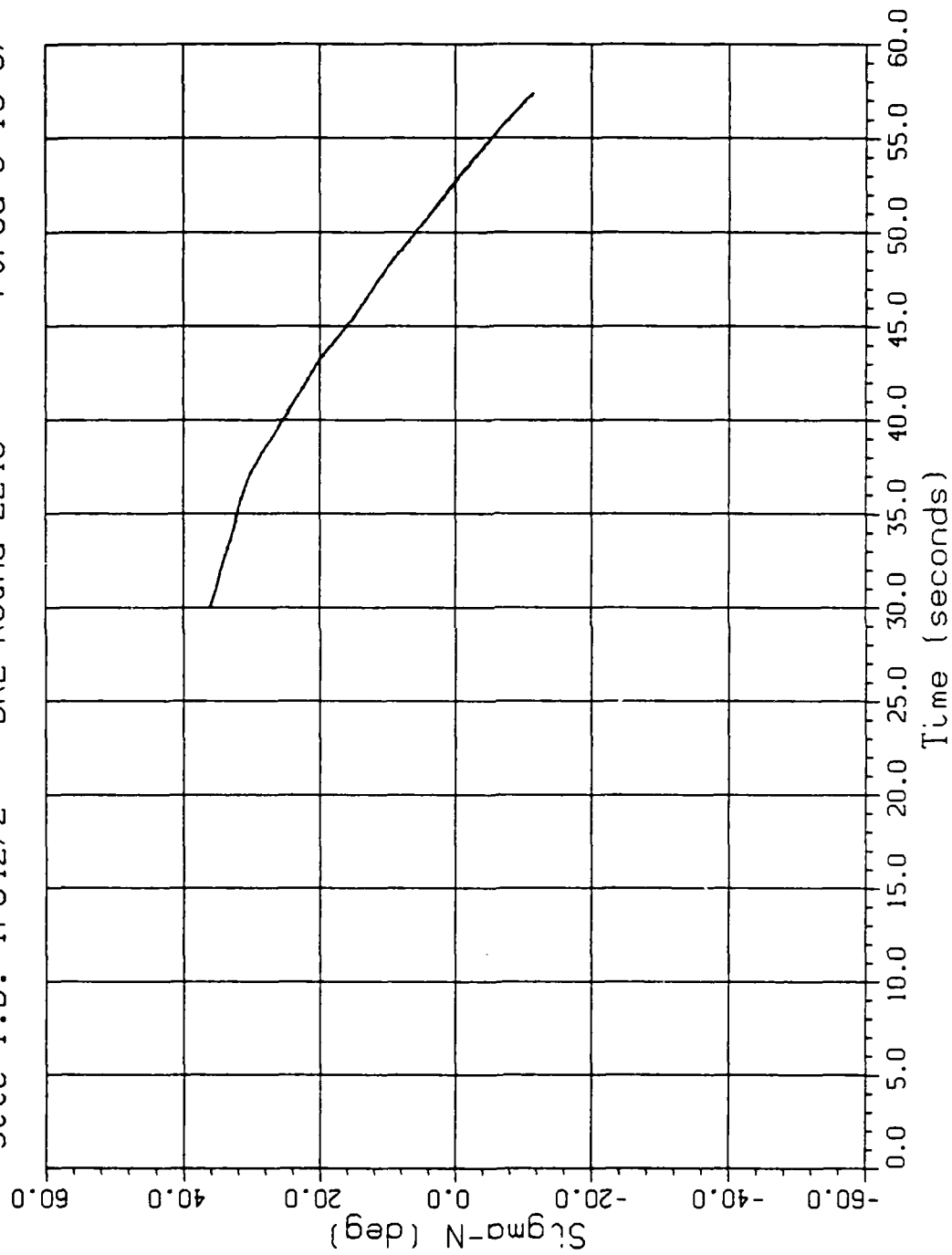


Figure 7. Yaw Angle Versus Time, Round 4272 (Yawsonde 2248)

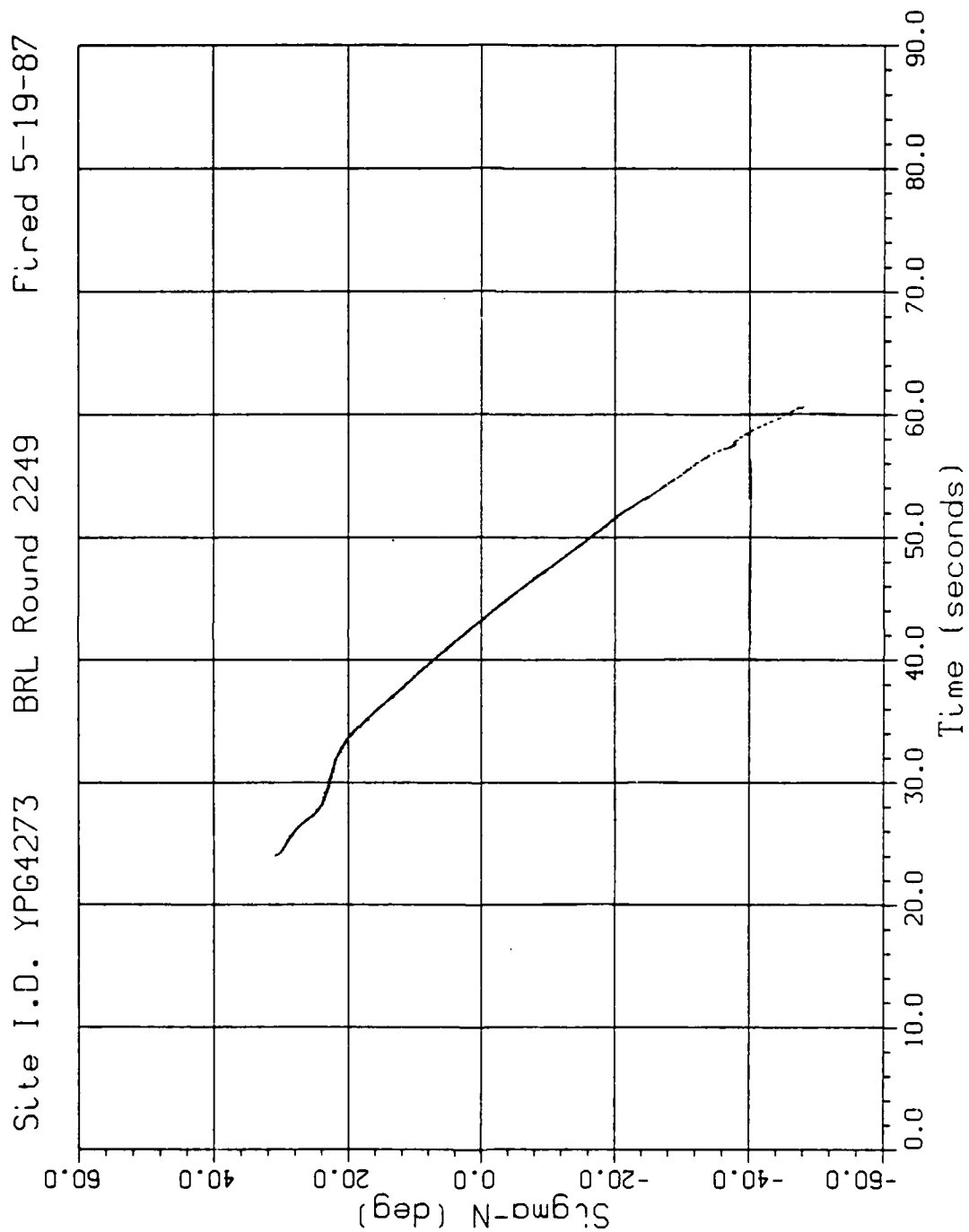


Figure 8. Yaw Angle Versus Time, Round 4273 (Yawsonde 2249)

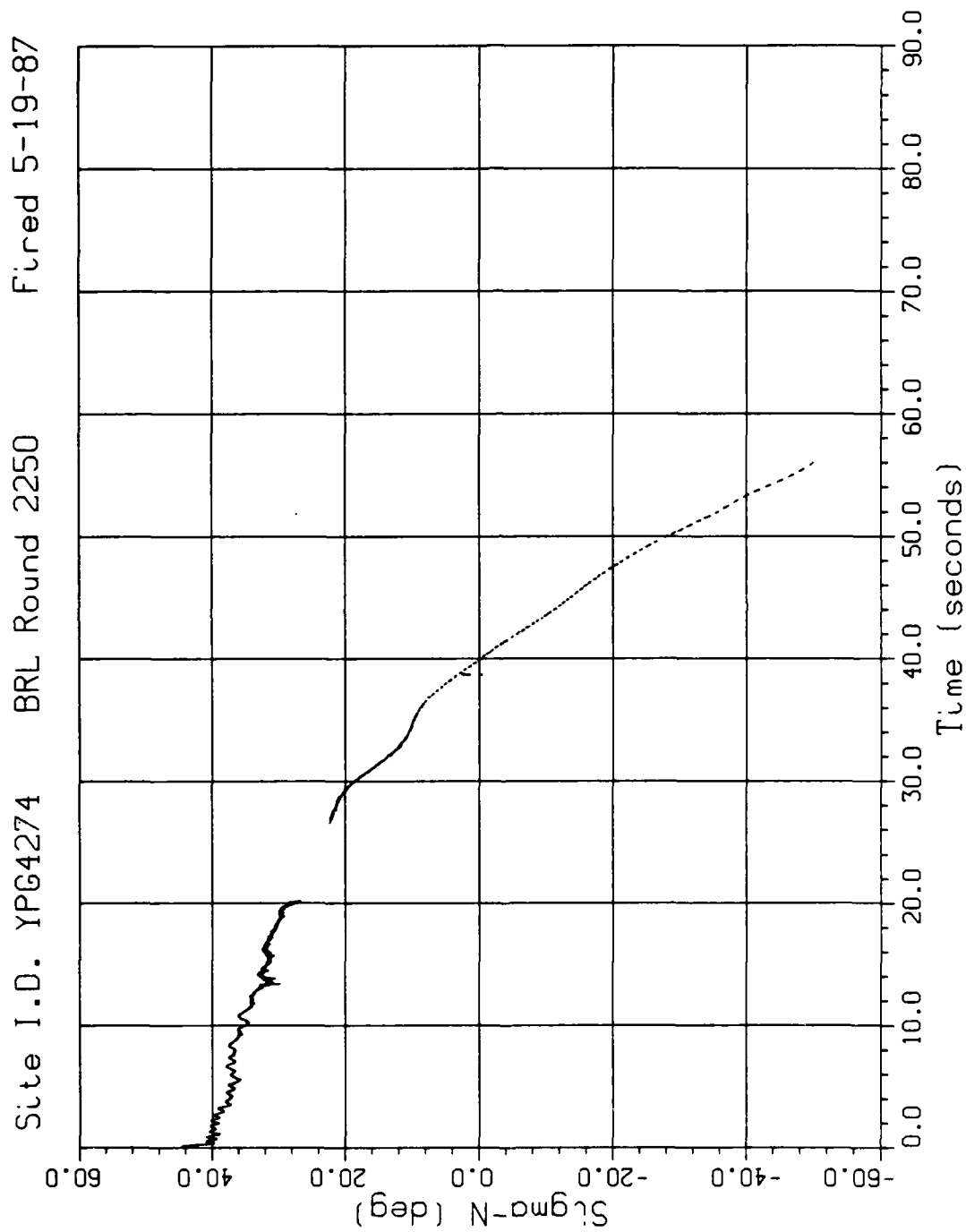


Figure 9. Yaw Angle Versus Time, Round 4274 (Yawsonde 2250)

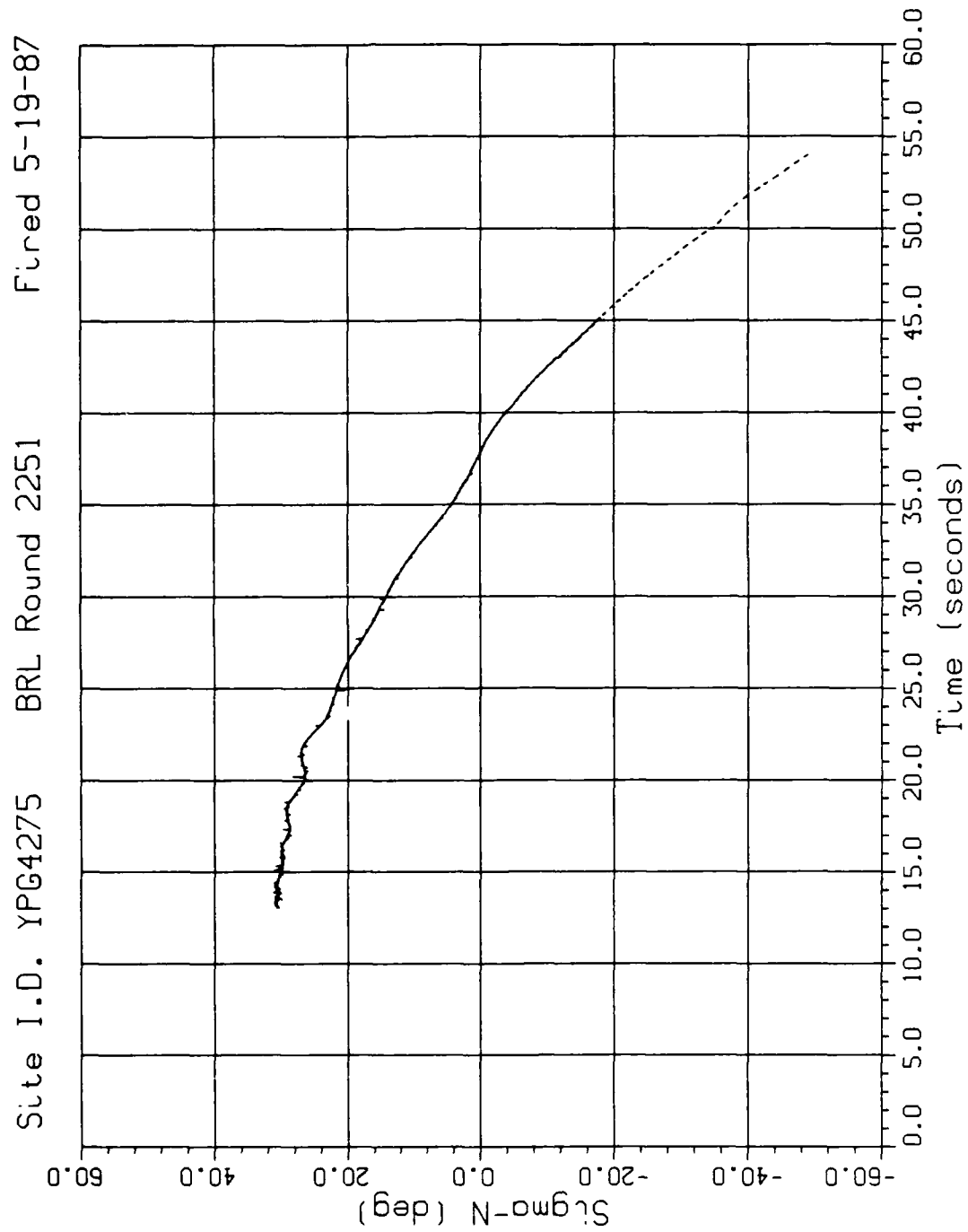


Figure 10. Yaw Angle Versus Time, Round 4275 (Yawsonde 2251)

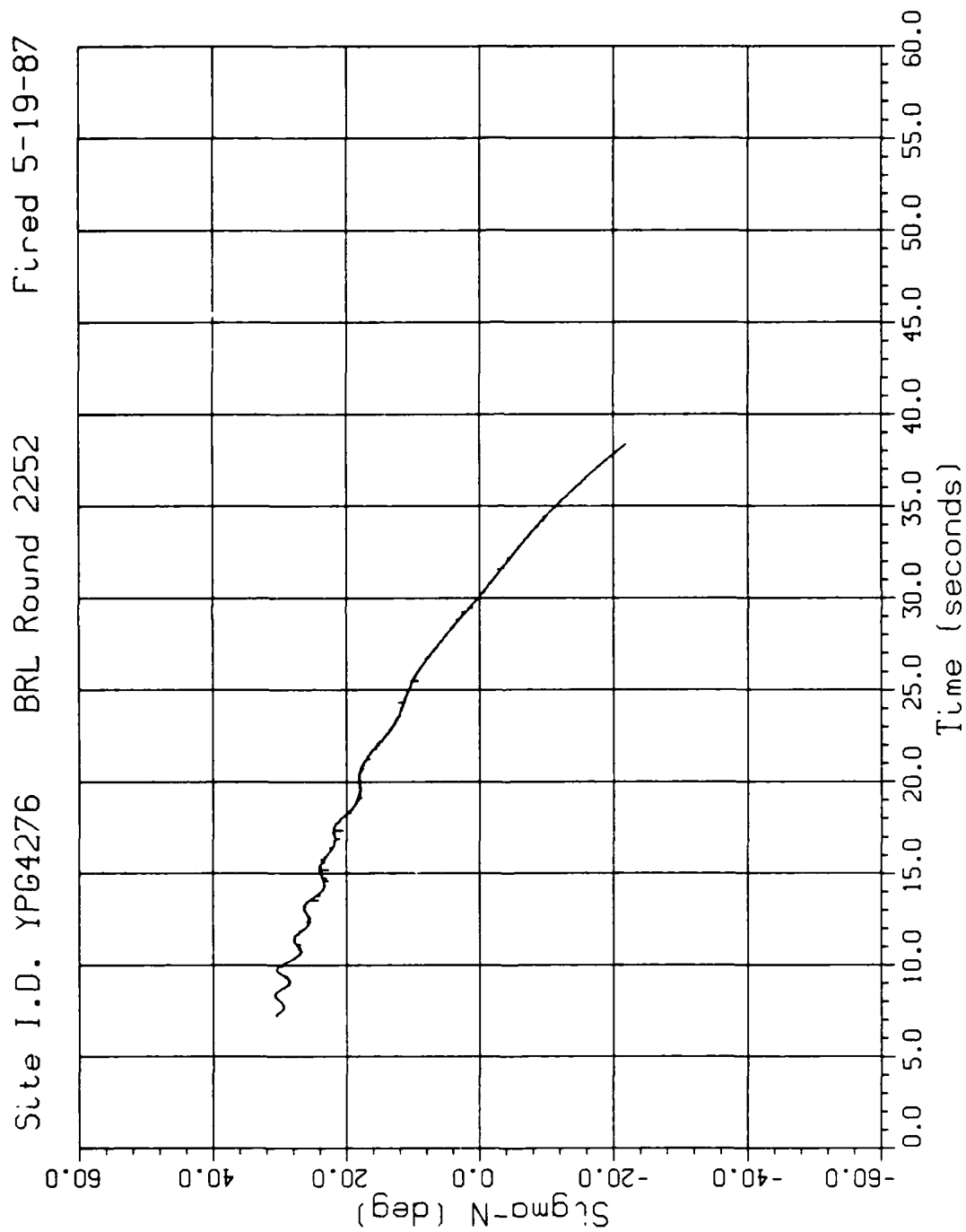


Figure 11. Yaw Angle Versus Time, Round 4276 (Yawsonde 2252)

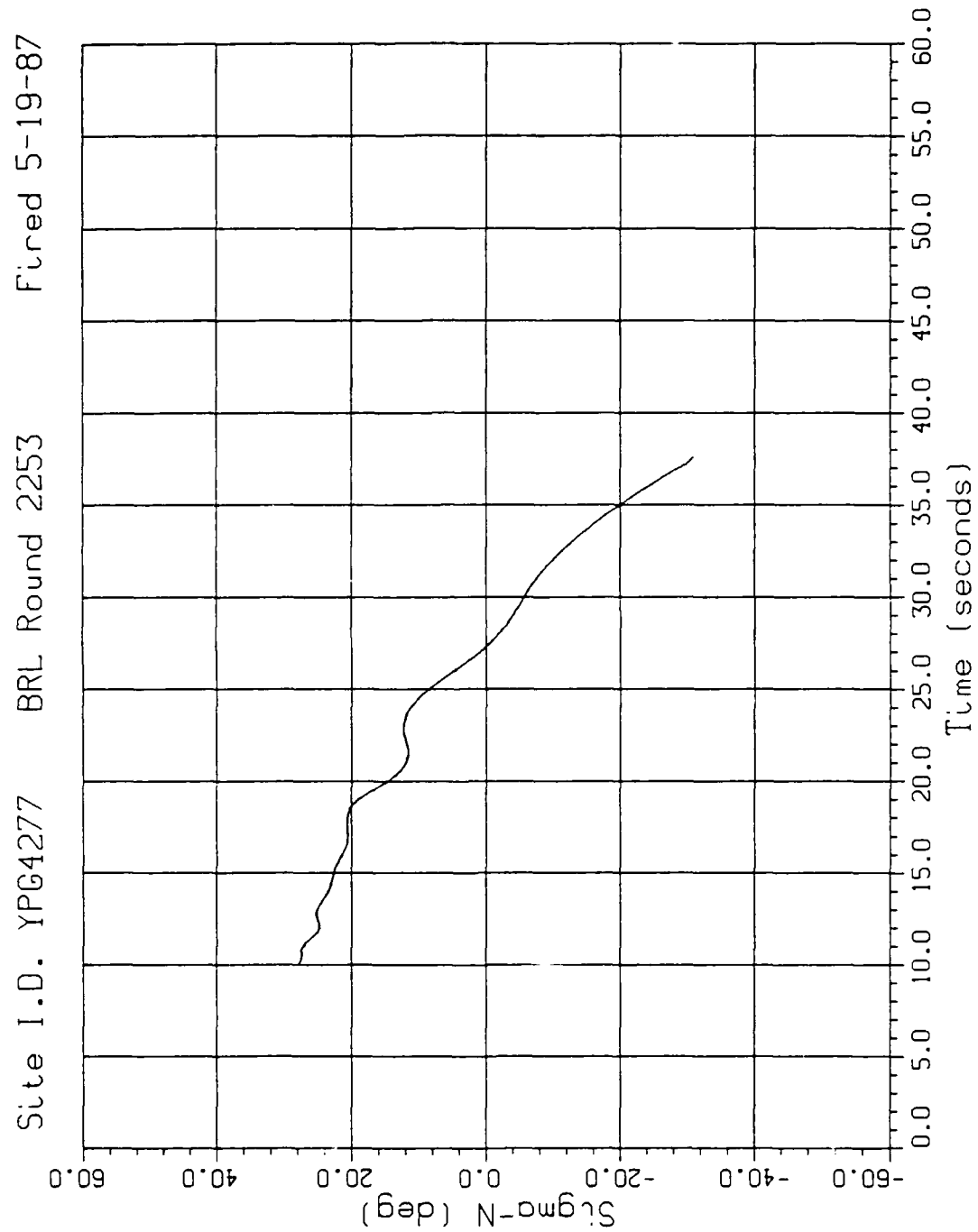


Figure 12. Yaw Angle Versus Time, Round 4277 (Yawsonde 2253)

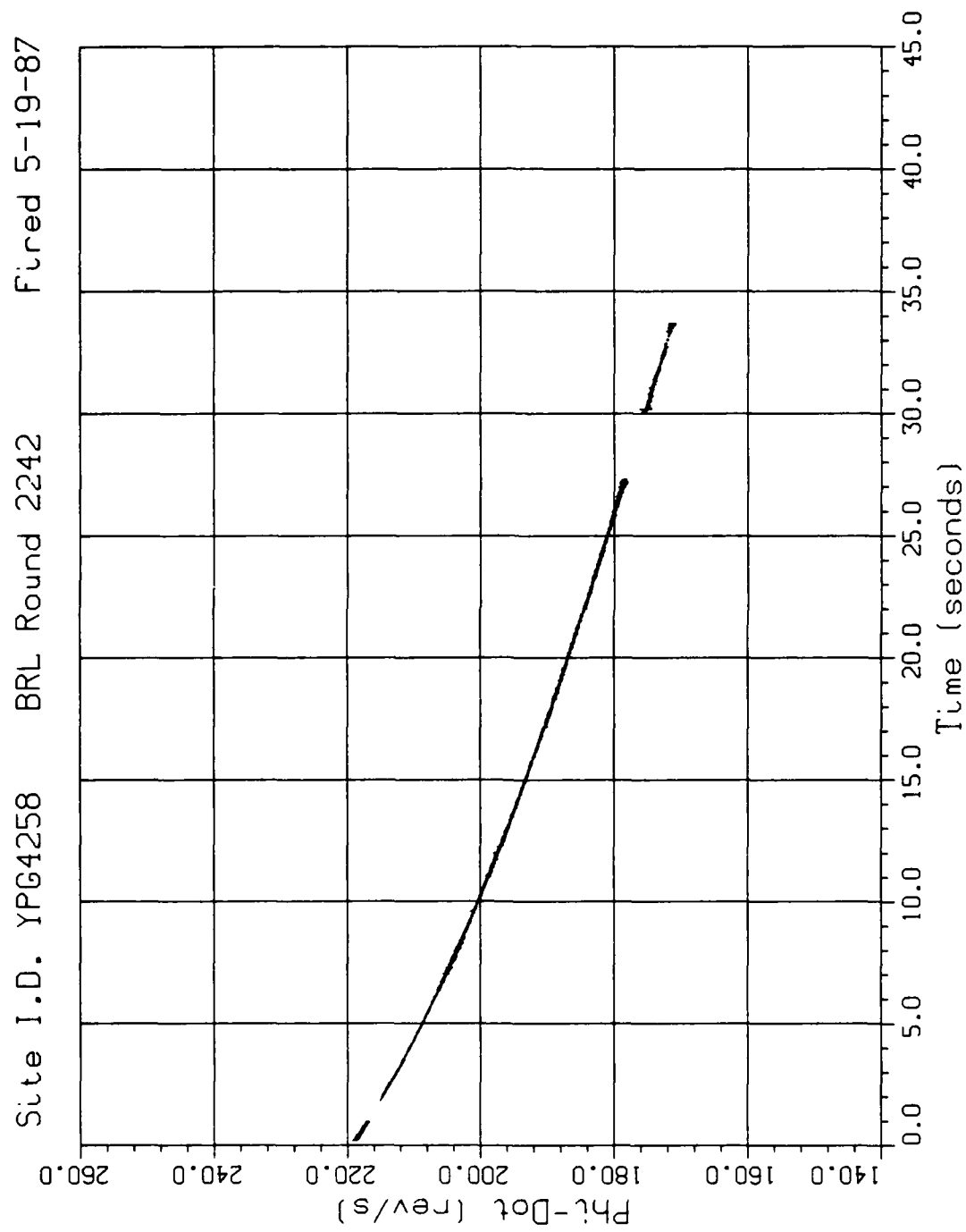


Figure 13. Spin Rate Versus Time, Round 4258 (Yawsonde 2242)

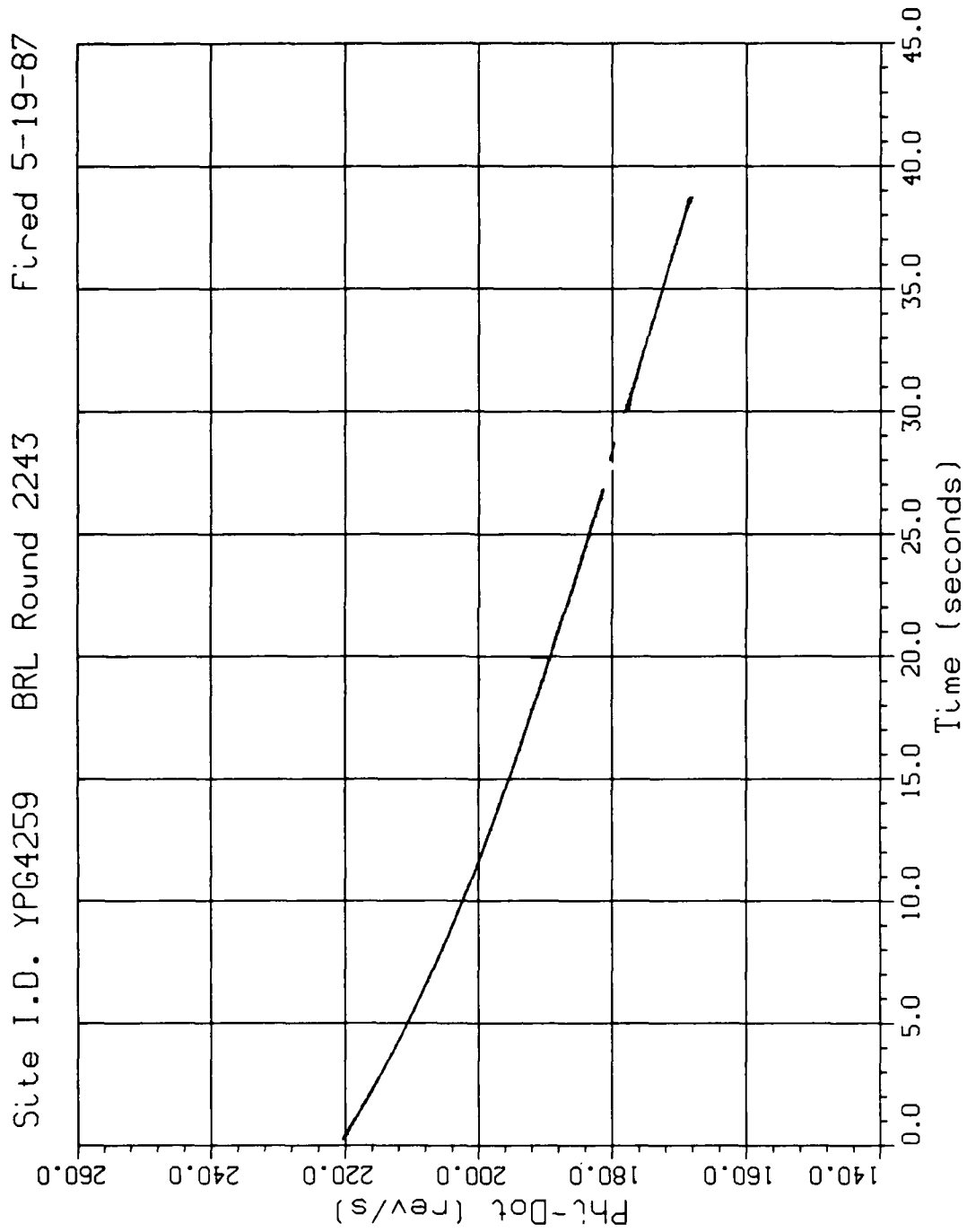


Figure 14. Spin Rate Versus Time, Round 4259 (Yawsonde 2243)

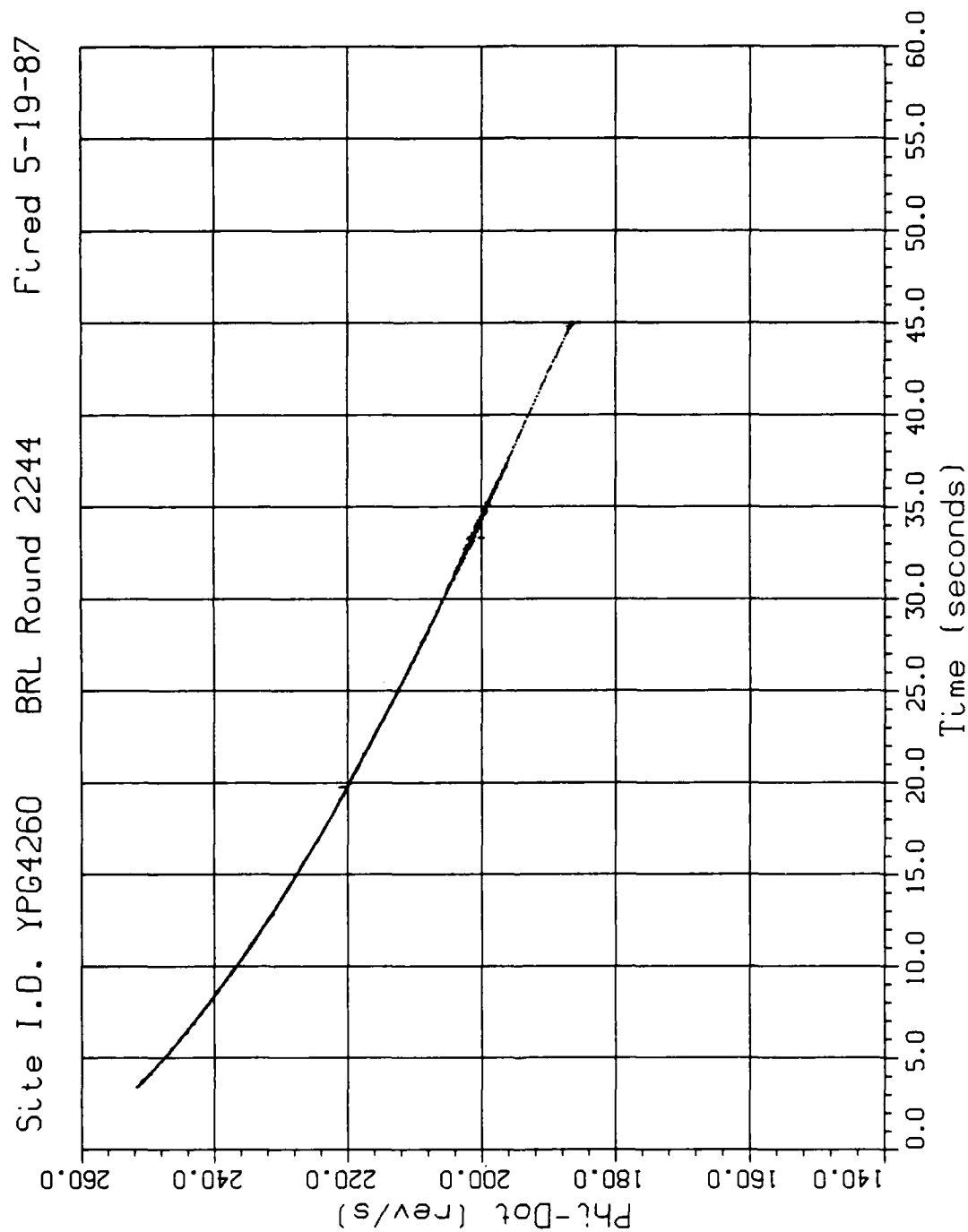


Figure 15. Spin Rate Versus Time, Round 4260 (Yawsonde 2244)

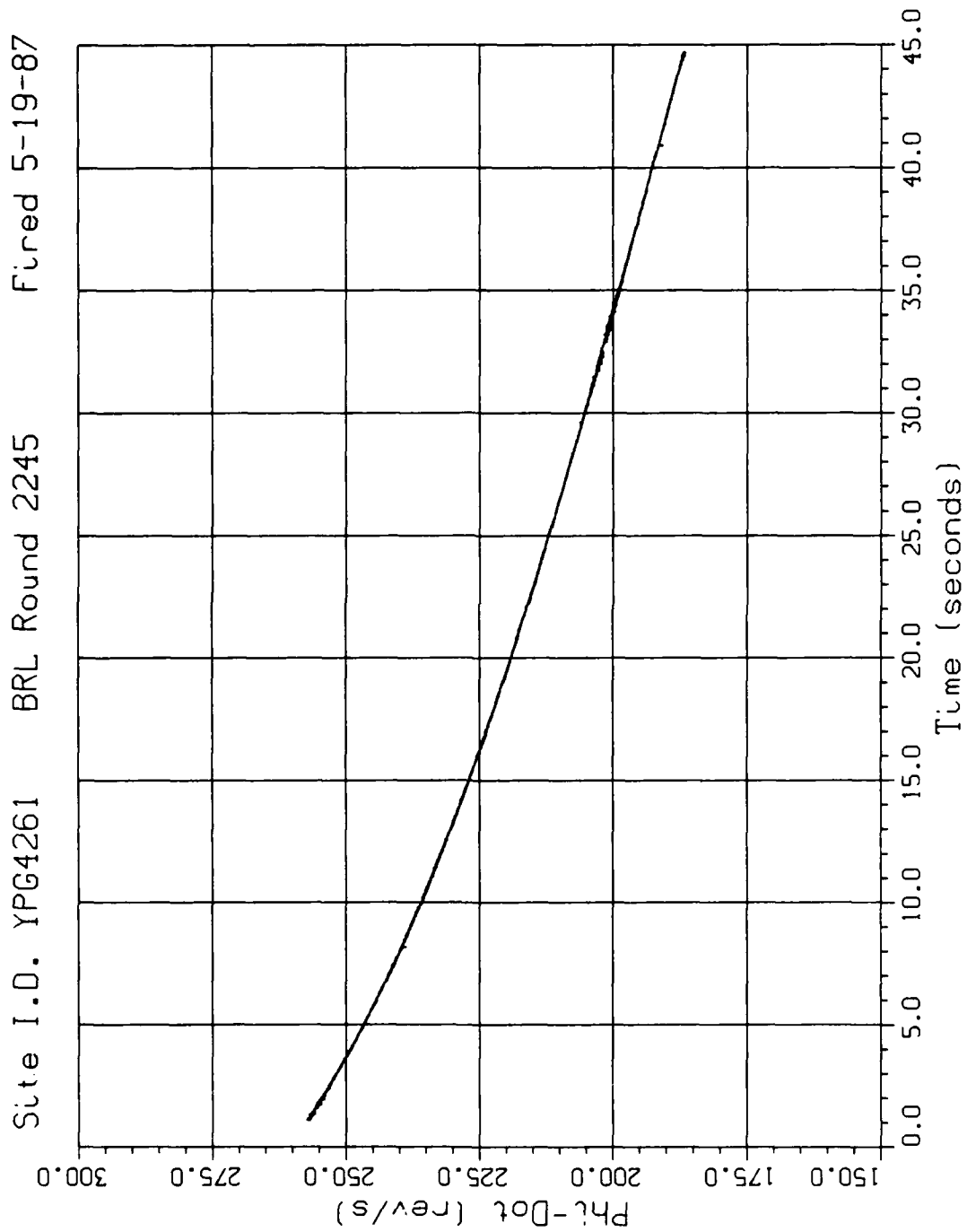


Figure 16. Spin Rate Versus Time, Round 4261 (Yawsonde 2245)

BRL 2246

Site ID: YPG 4262    Fired: 19 May, 1987

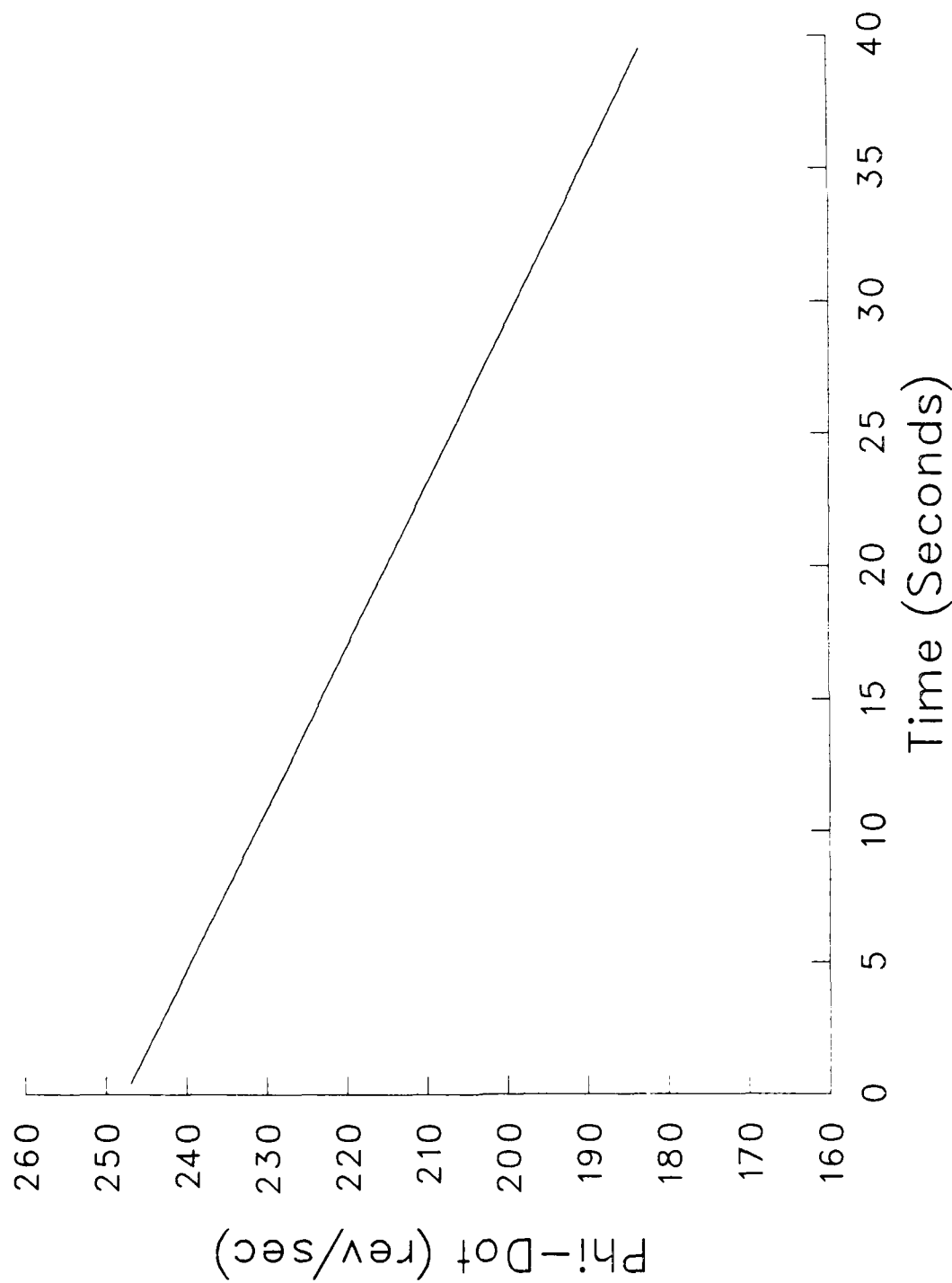


Figure 17. Spin Rate Versus Time, Round 4262 (Yawsonde 2246)

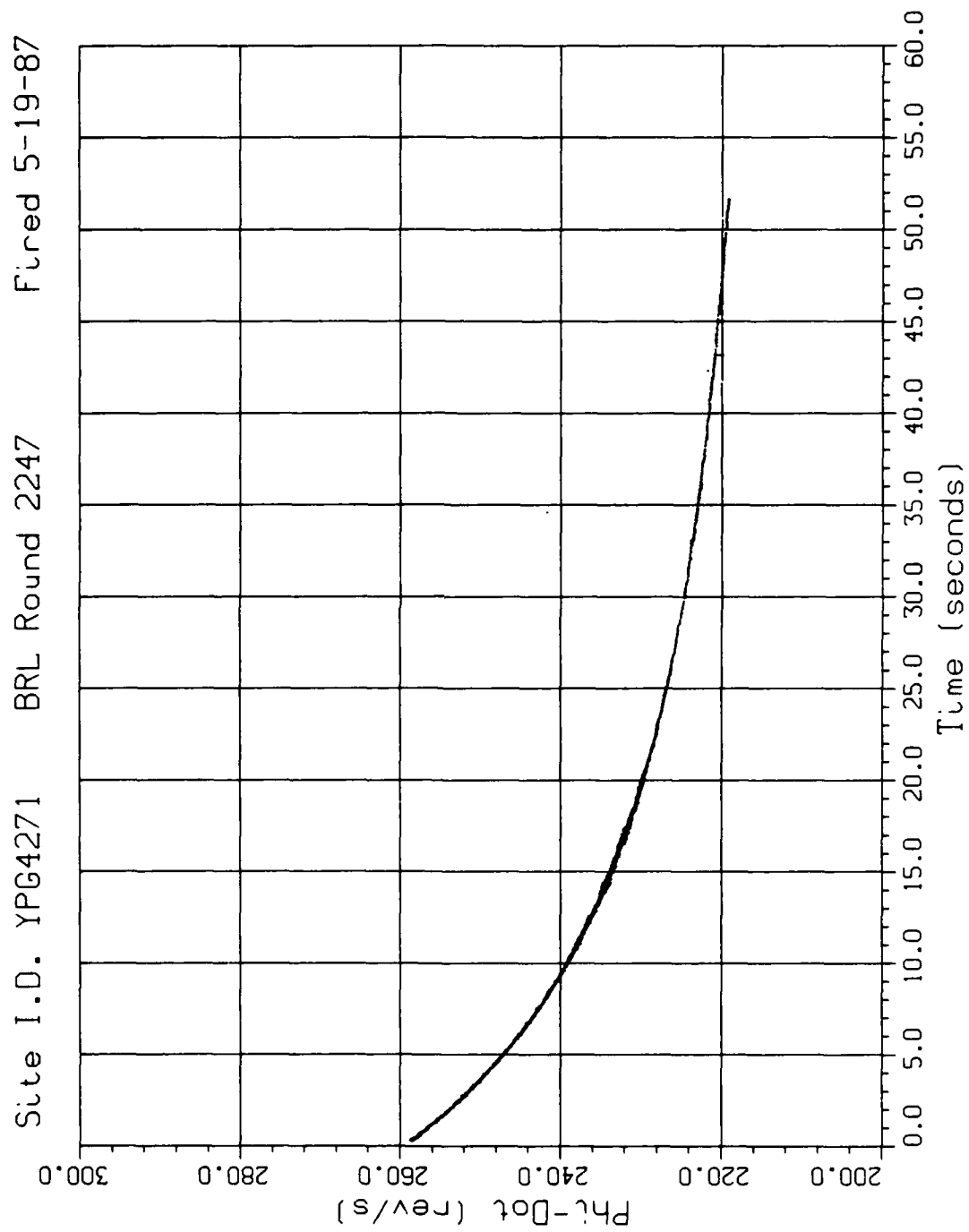


Figure 18. Spin Rate Versus Time, Round 4271 (Yawsonde 2247)

BRL 2248

Site ID: YPG 4272    Fired: 19 May, 1987

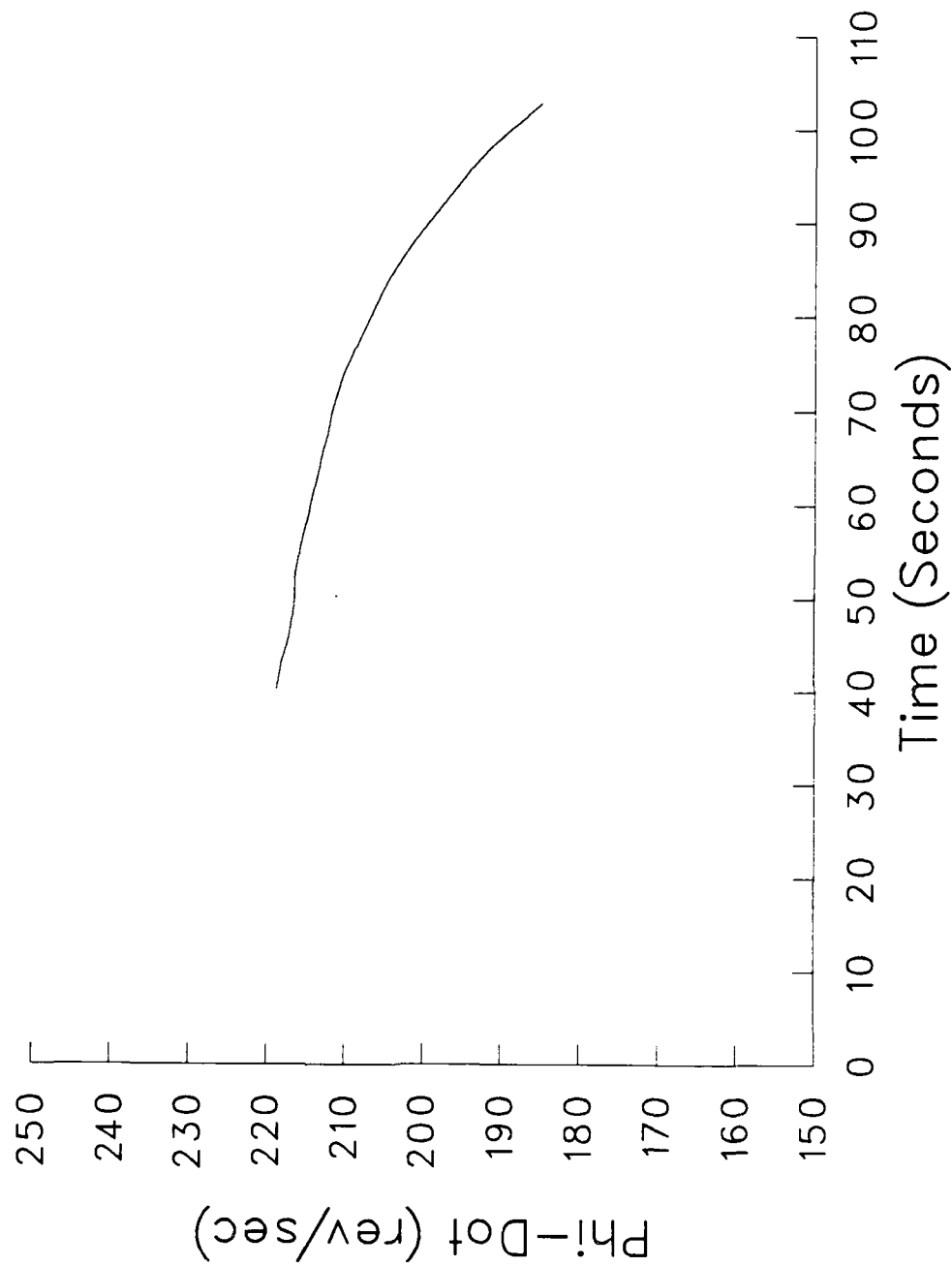


Figure 19. Spin Rate Versus Time, Round 4272 (Yawsonde 2248)

BRL 2249  
Site ID: YPG 4273    Fired: 19 May, 1987

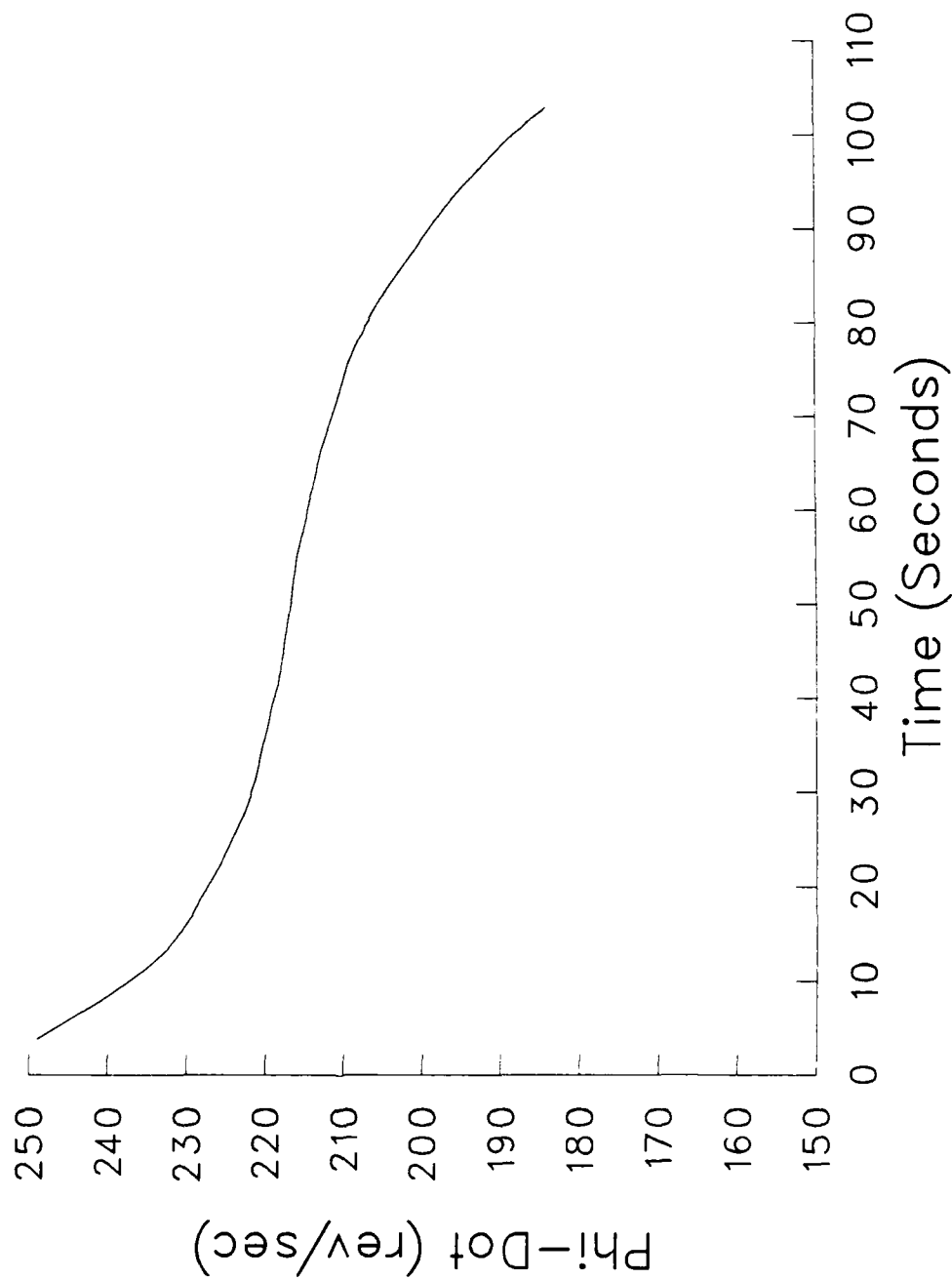


Figure 20. Spin Rate Versus Time, Round 4273 (Yawsonde 2249)

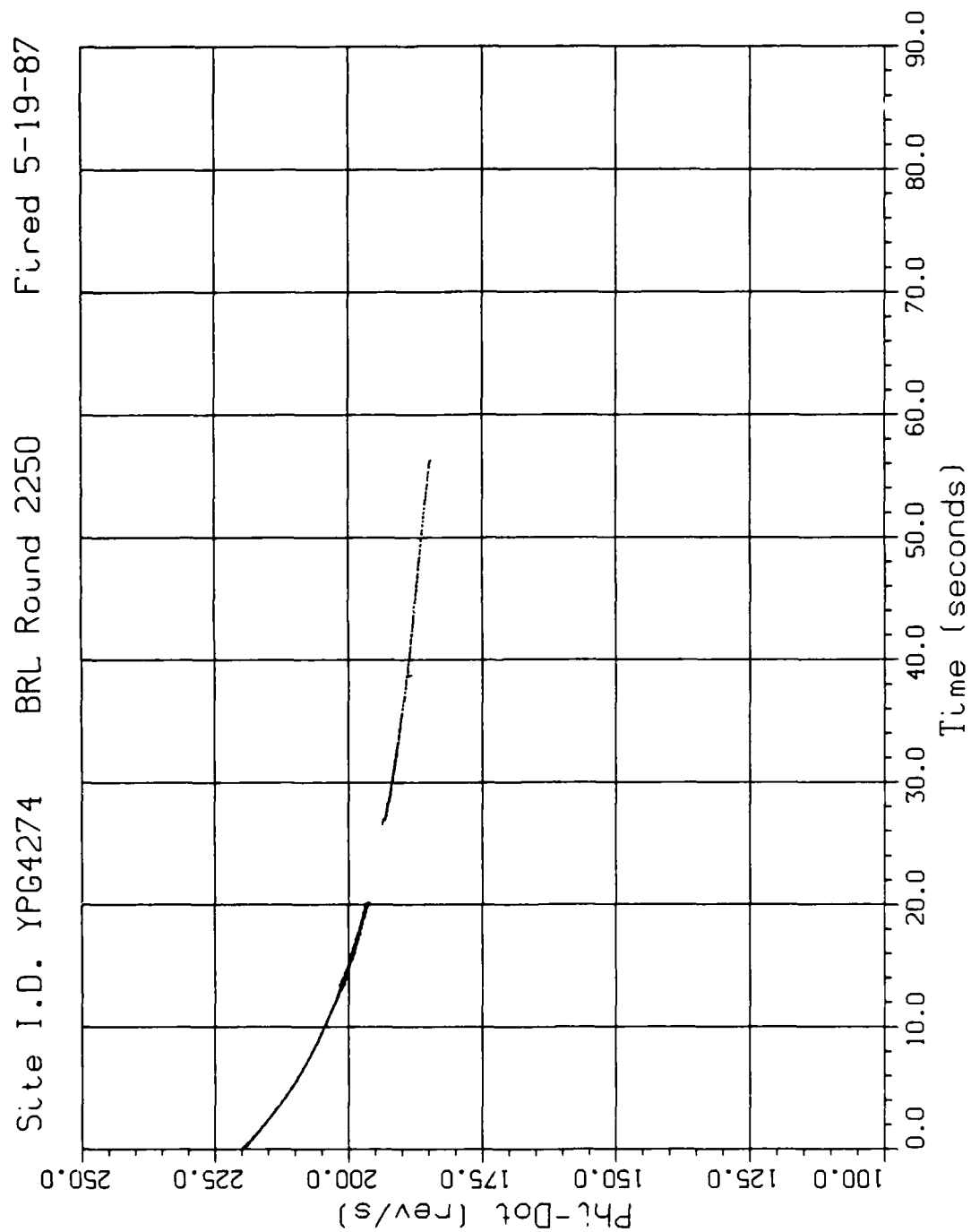


Figure 21. Spin Rate Versus Time, Round 4274 (Yawsonde 2250)

BRL 2251  
Site ID: YPG 4275    Fired: 19 May, 1987

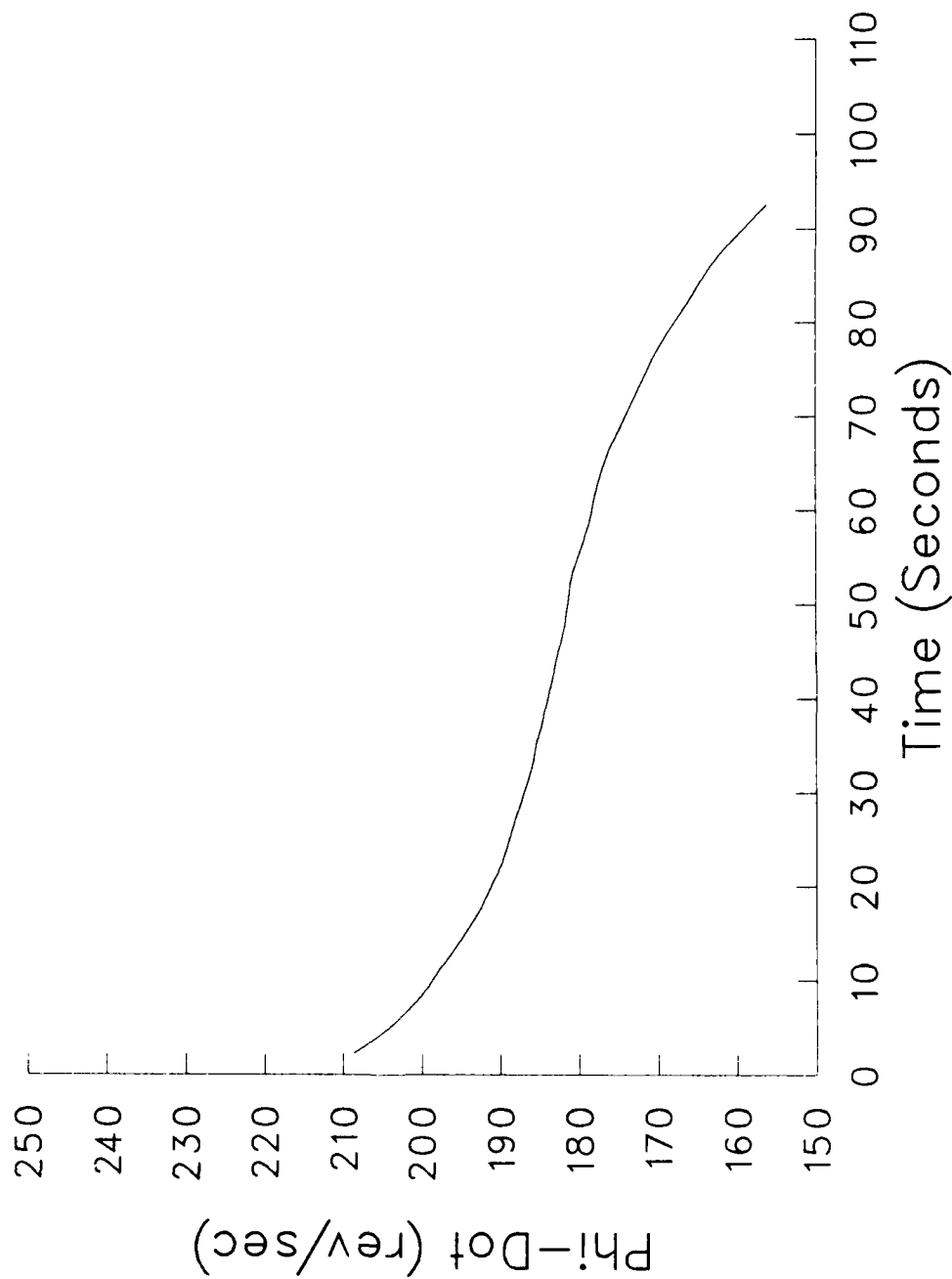


Figure 22. Spin Rate Versus Time, Round 4275 (Yawsonde 2251)

BRL 2252

Site ID: YPG 4276    Fired: 19 May, 1987

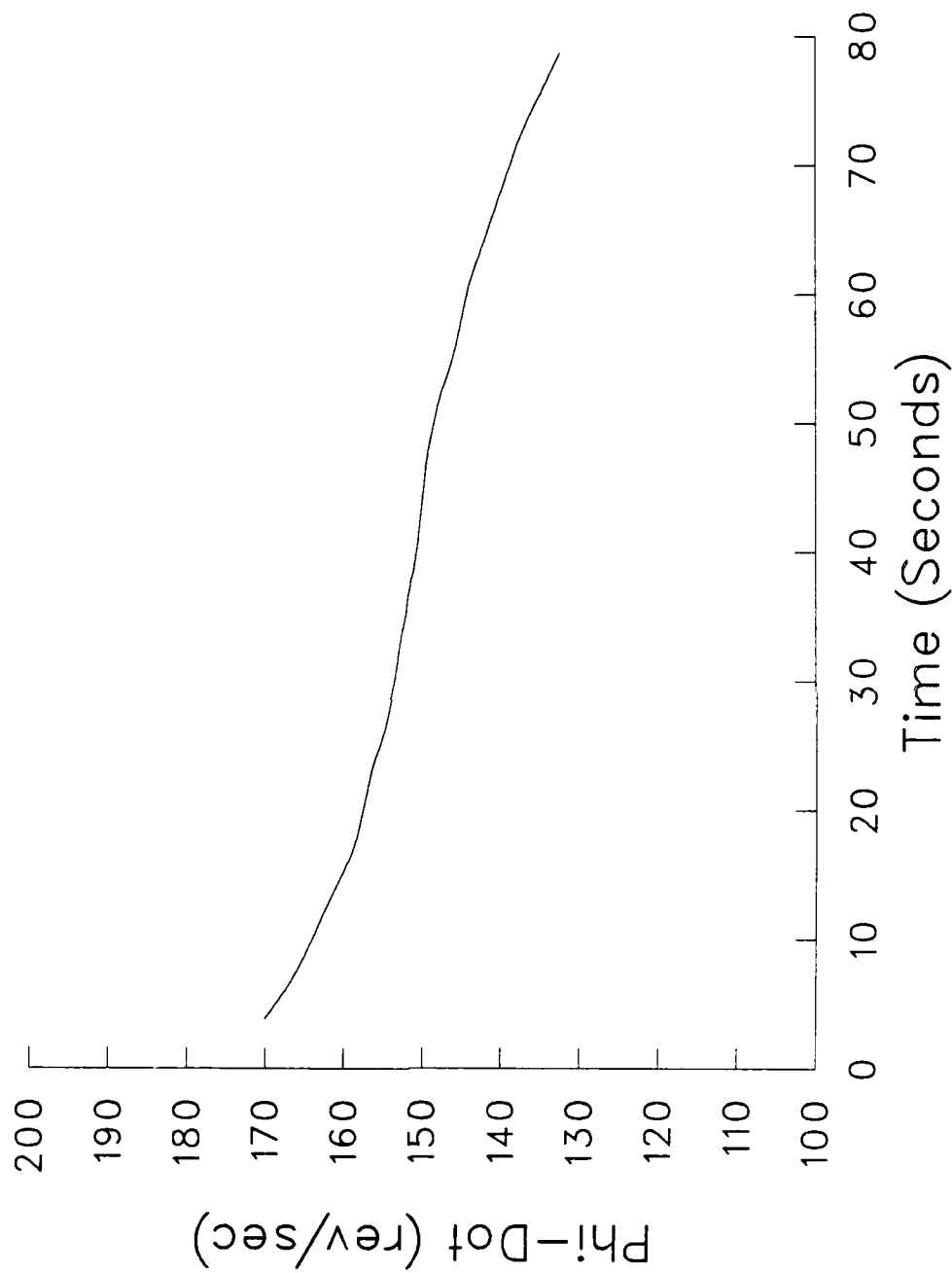


Figure 23. Spin Rate Versus Time, Round 4276 (Yawsonde 2252)

BRL 2253  
Site ID: YPG 4277    Fired: 19 May, 1987

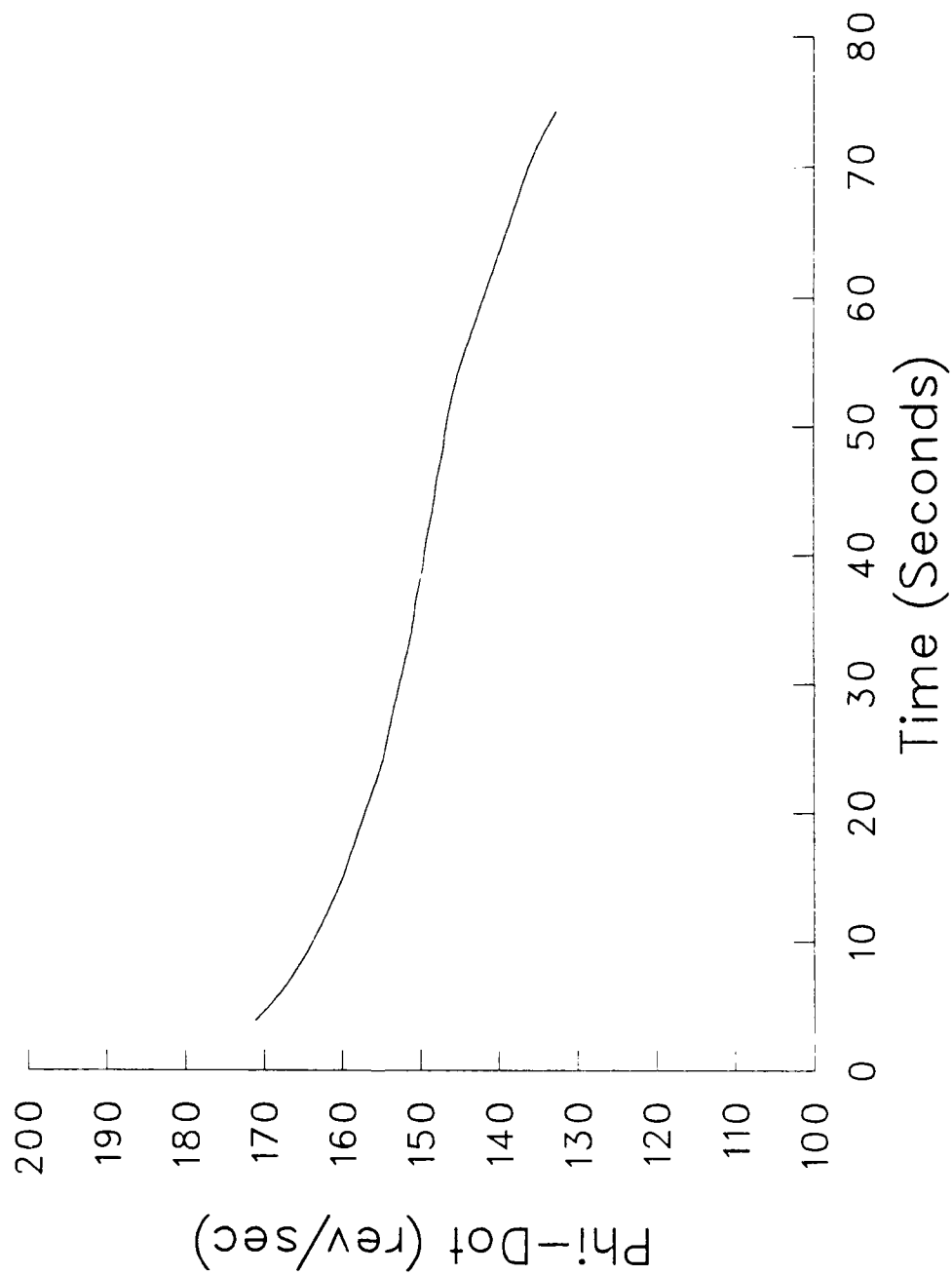


Figure 24. Spin Rate Versus Time, Round 4277 (Yawsonde 2253)

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1. Test Program Request (TPR) (LCU-S-2973) Revision 1 to Amend. 2, Supl. 6 for Projectile, 155mm: Extended Range, DP, XMS64 (TECOM Project No. 2-MU-003-864-003), ARDEC, Dover, New Jersey, 13 May 1987.
2. Mermagen, W. H. and Clay, W. H., "The Design of a Second Generation Yawsonde," MR 2368,, U.S. Army Ballistic Research Laboratory, Aberdeen Proving Ground, Maryland, April 1974. (AD 780064)
3. Clay, W. H.,, "A Precision Yawsonde Calibration Technique," MR 2263, U.S. Army Ballistic Research Laboratory, Aberdeen Proving Ground, Maryland, January 1973. (AD 758158)
4. Murphy, C. H., "Effects of Large High-Frequency Angular Motion of a Shell on the Analysis of Its Yawsonde Records," MR 2581, U.S. Army Ballistic Research Laboratory, Aberdeen Proving Ground, Maryland, February 1976. (AD 0094210)

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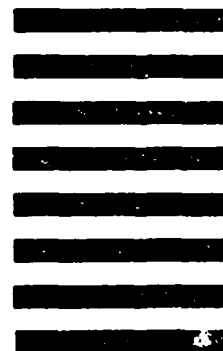


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