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ANALYSIS OF TILT DATA OF ANTIAIRCRAFT GUN MOUNTS FROM HITVAL FI--ETC(U)
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J. A. Ross, *Project Leader*
A. J. Pemberton

December 1974

This report has been prepared by the Systems Evaluation Division of the Institute for Defense Analyses in response to the Weapons Systems Evaluation Group Task Order DAHC15 73 C 0200 T-182, revised 18 September 1972.

In the work under this Task Order, the Institute has been supported by military personnel assigned by WSEG.

INSTITUTE FOR DEFENSE ANALYSES
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ANALYSIS OF TILT DATA OF ANTIAIRCRAFT GUN MOUNTS FROM THE HITVAL FIELD TEST

A. INTRODUCTION

The object of the HITVAL[1] program is to verify the validity (or lack thereof) of mathematical models used to calculate the probability of hit of aircraft fired at by antiaircraft guns. To accomplish this validation of models, a field test ~~has been~~ was conducted in which aircraft were flown past antiaircraft guns, while their flight paths were recorded by cinetheodolites. The antiaircraft gun crews simulated fire at the aircraft, and instrumentation recorded (among other things) the gun pointing angles. The rounds fired were "break-up ammunition," which produces the flash, smoke, dust, and recoil of lethal rounds but disintegrates soon after leaving the gun barrel. Given the aircraft flight paths, the gun pointing angles, and ballistics data, a probability of hit can be calculated, which can then be used as a standard of comparison for the mathematical models. (cont on p2)

The angle of the gun barrel is measured relative to the mount (or base) of the gun. This instrumentation is considered to be very accurate, but since the gun mount vibrates during firing, its tilt must be measured. To ensure a sufficiently accurate gun pointing angle, it is required that the accuracy of the mount tilt measurement be better than 0.7 mrad.[2]

It was feared that during firing the instrumentation measuring the tilt of the mount might oscillate independently of the mount, causing spurious vibration to be recorded. This noise in the recorded data could cause incorrect gun pointing angles to be calculated, thus distorting the results of the field test. Thus, in the requirements for the reduced data from the field tests,[3] provision was made for reporting both the tilt measured by the instrumentation, and a smoothed tilt computed from the measured values by passing them through low-pass filters.

Three different antiaircraft guns were used in the HITVAL I field test: the ZU-23 twin 23 mm, the S-60 single barrel 57 mm, and the 5PFZ-B (Flak Panzer) twin 35 mm. The smoothed tilt data were computed using cutoff frequencies of 33 Hz for the ZU-23, 5 Hz for the S-60, and 20 Hz for the 5PFZ-B.

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1. *Design of a Field Test for Probability of Hit by Antiaircraft Guns*, IDA Paper P-921 (WSEG Report 197), February 1973.

2. WSEG Report 197, op. cit.

3. *Requirements for Reduced Data From Field Test–Probability of Hit by Antiaircraft Guns*, IDA Paper P-951, July 1973.

This paper reports the findings of an analysis of the mount tilt data as recorded by the instrumentation during preliminary trials of the field test. The analysis was conducted to determine if the data need to be smoothed (i.e., is there high-frequency noise in the data?).

B. RESULT

The result of the mathematical examination of the spectral structure of the power in the mount tilt data is that the data do contain significant high-frequency noise, and therefore the filtering procedure is necessary.

C. ANALYSIS OF THE DATA

Two methods of analysis were used to examine the spectral structure of the power in the tilt data: (1) relative power spectral density (PSD) and (2) low-pass filters. The PSD method was used to indicate the relative power at each frequency. (The output was normalized so that the maximum amplitude in each case was 1.0; frequencies less than 2 Hz were suppressed.) The low-pass filters were used to determine how closely the filtered tilt values approach the measured values.[4] (The investigated cutoff frequencies–10, 20, and 30 Hz–were selected after the PSD analysis indicated that most of the power was at frequencies less than 30 to 35 Hz.) The data investigated consisted of the roll, yaw, and pitch measurements taken with autocollimators from a point on the mount of the gun. The data were sampled 100 times per second and measured to the nearest 1/3 mrad.

The instrumentation attached to the mount to measure tilt has natural frequencies that are higher than the cyclic rate of fire for each gun. Thus, the cutoff frequencies used in preparing the smoothed tilt data reported from the field test were chosen to be slightly higher than each gun's cyclic rate of fire. If movement of greater frequency were discovered, it would be attributed to spurious movement of the instrumentation.

Figures 1 through 12 are typical of the output for the two methods of analyses. For each of the three guns, four graphs are shown–one showing the PSD as a function of frequency for roll, yaw, and pitch; and the other three (one each for roll, yaw, and pitch) comparing filtered and unfiltered signals.

The graphs for the ZU-23 show little power beyond the cutoff frequency of 33 Hz. The PSD graph (Figure 1) shows most of the power at less than 35 Hz; the low-pass filter graphs (Figures 2 through 4), with a cutoff frequency of 30 Hz, show the smoothed data following the raw data fairly well. For the ZU-23, therefore, it seems to make little difference whether the filtered or raw data are used.

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4. For additional discussion of the filters employed in this analysis, see the Appendix.

The necessity for using the smoothed data is more obvious in the cases of the S-60 and 5PFZ-B guns. For the S-60, the PSD graph (Figure 5) shows considerable power beyond the gun's 5-Hz cutoff frequency; the low-pass filter graphs (Figures 6 through 8), with a cutoff frequency of 10 Hz, show clearly that a large high-frequency component has been removed. For the 5PFZ-B, the PSD graph (Figure 9) shows significant power at frequencies greater than 20 Hz; the low-pass filter graphs (Figures 10 through 12), with a cutoff frequency of 20 Hz, show that the filtered signal varies markedly from the raw data, again indicating the presence of a large high-frequency component.

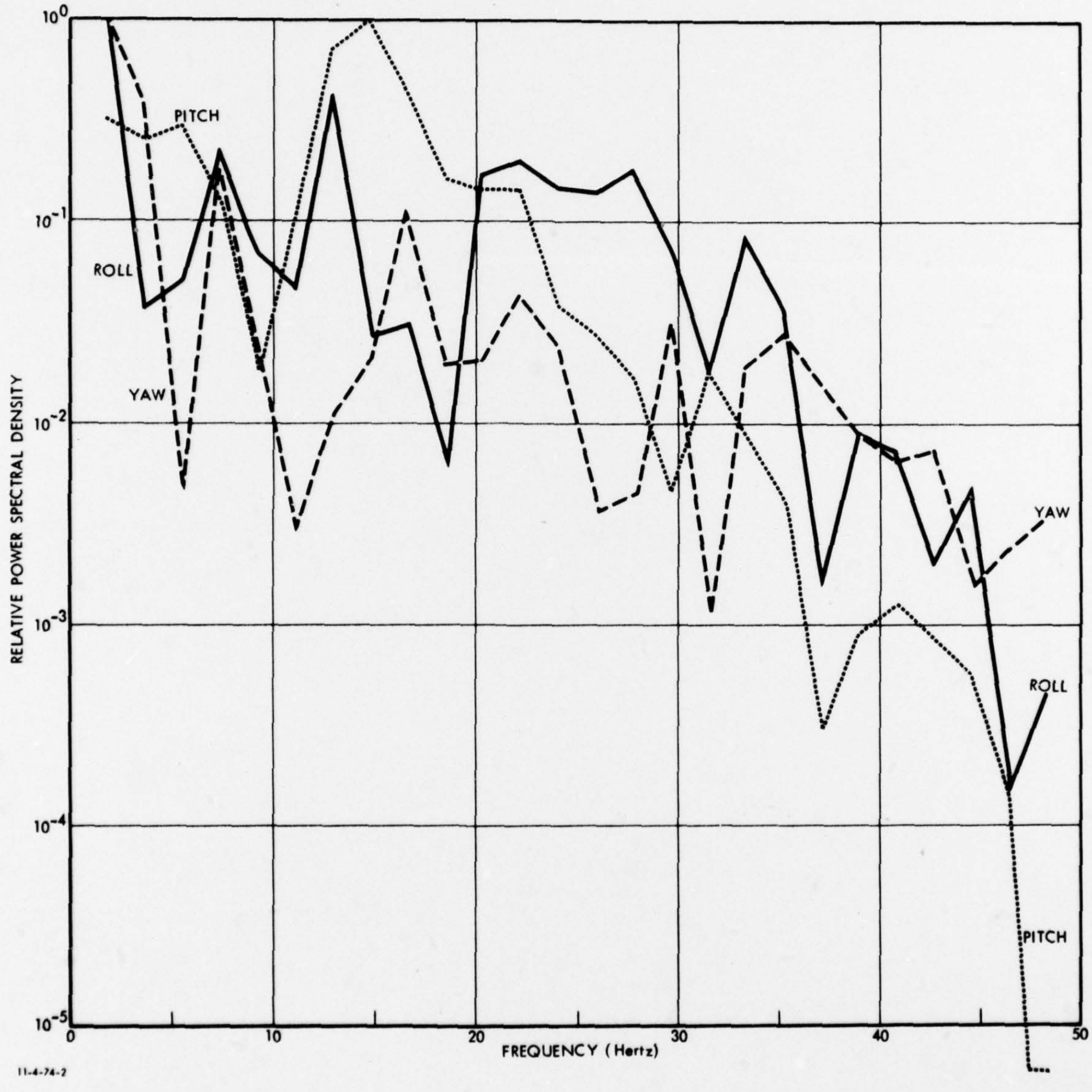

Figure 1. Spectral Density for the ZU-23

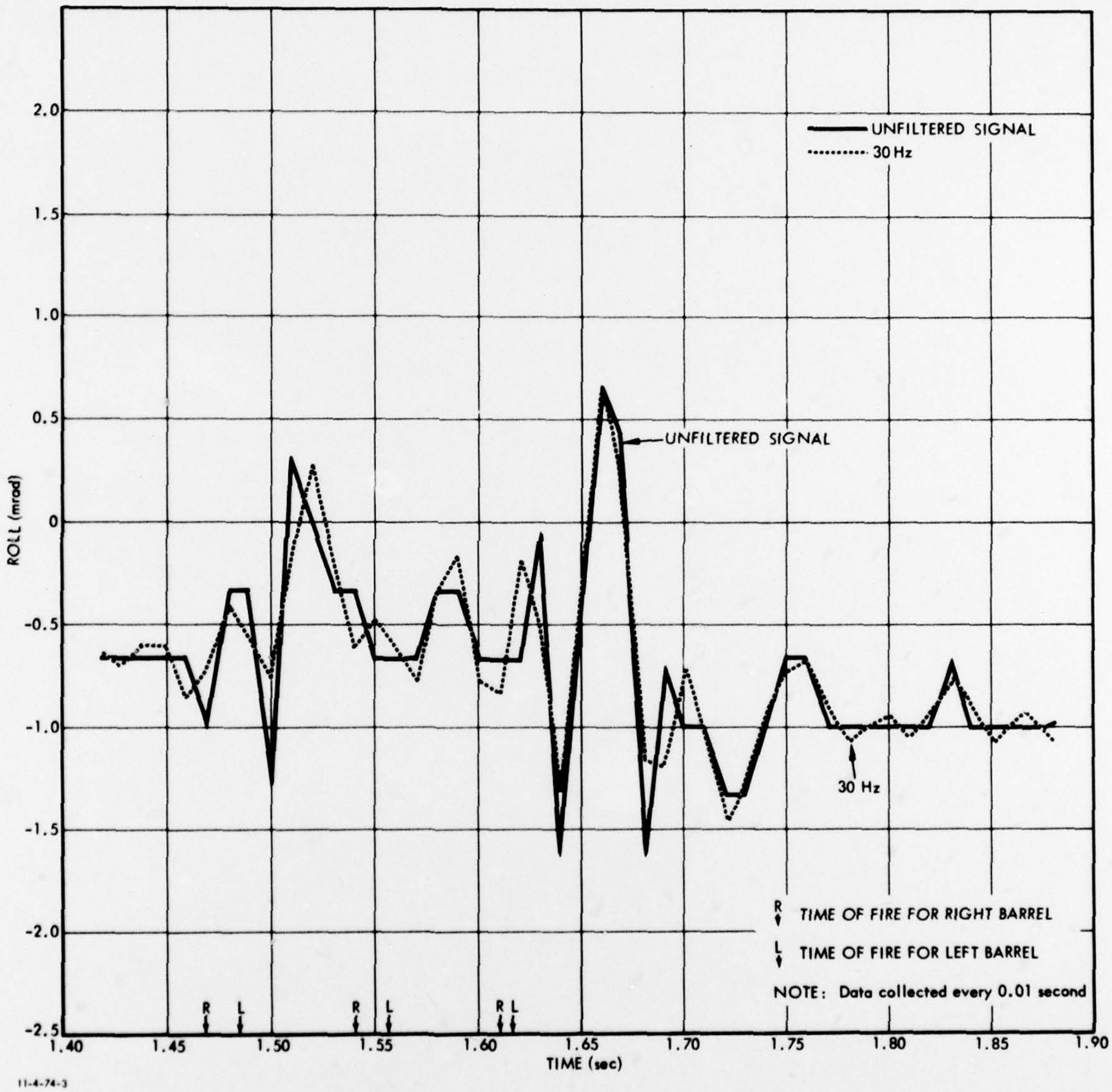

Figure 2. ZU-23 Roll Data at 30-Hz Cutoff Frequency

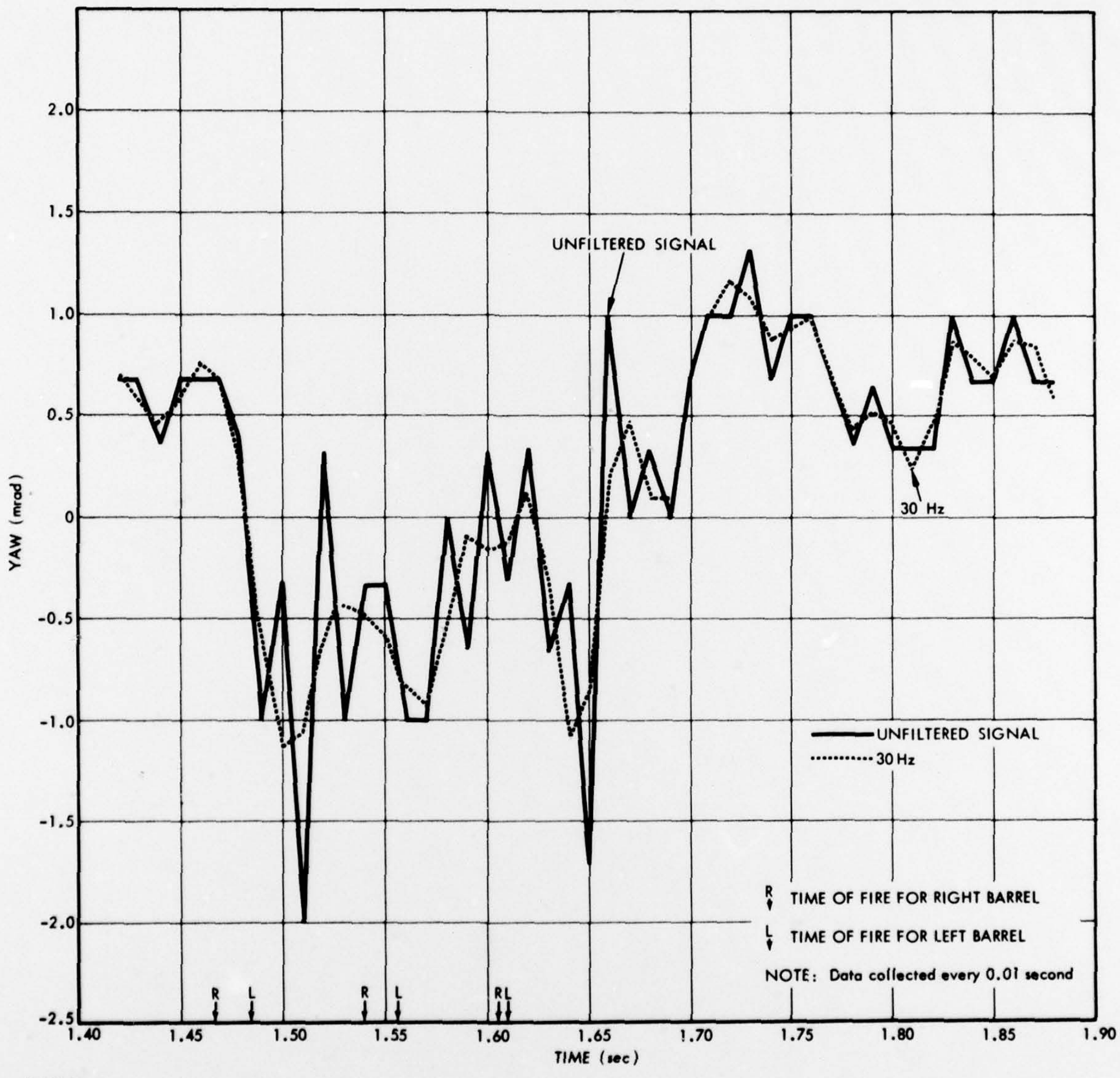

Figure 3. ZU-23 Yaw Data at 30-Hz Cutoff Frequency

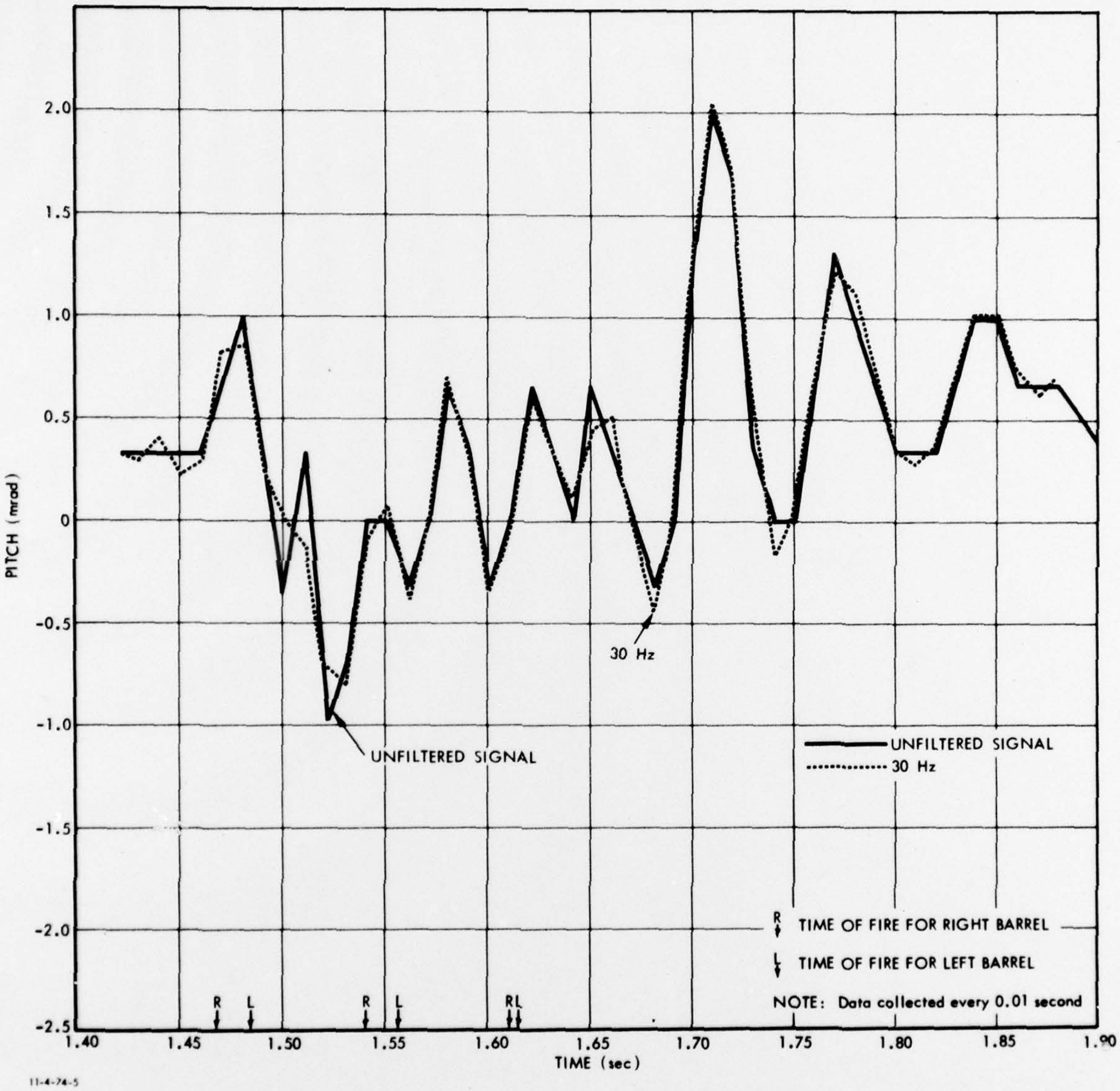

Figure 4. ZU-23 Pitch Data at 30-Hz Cutoff Frequency

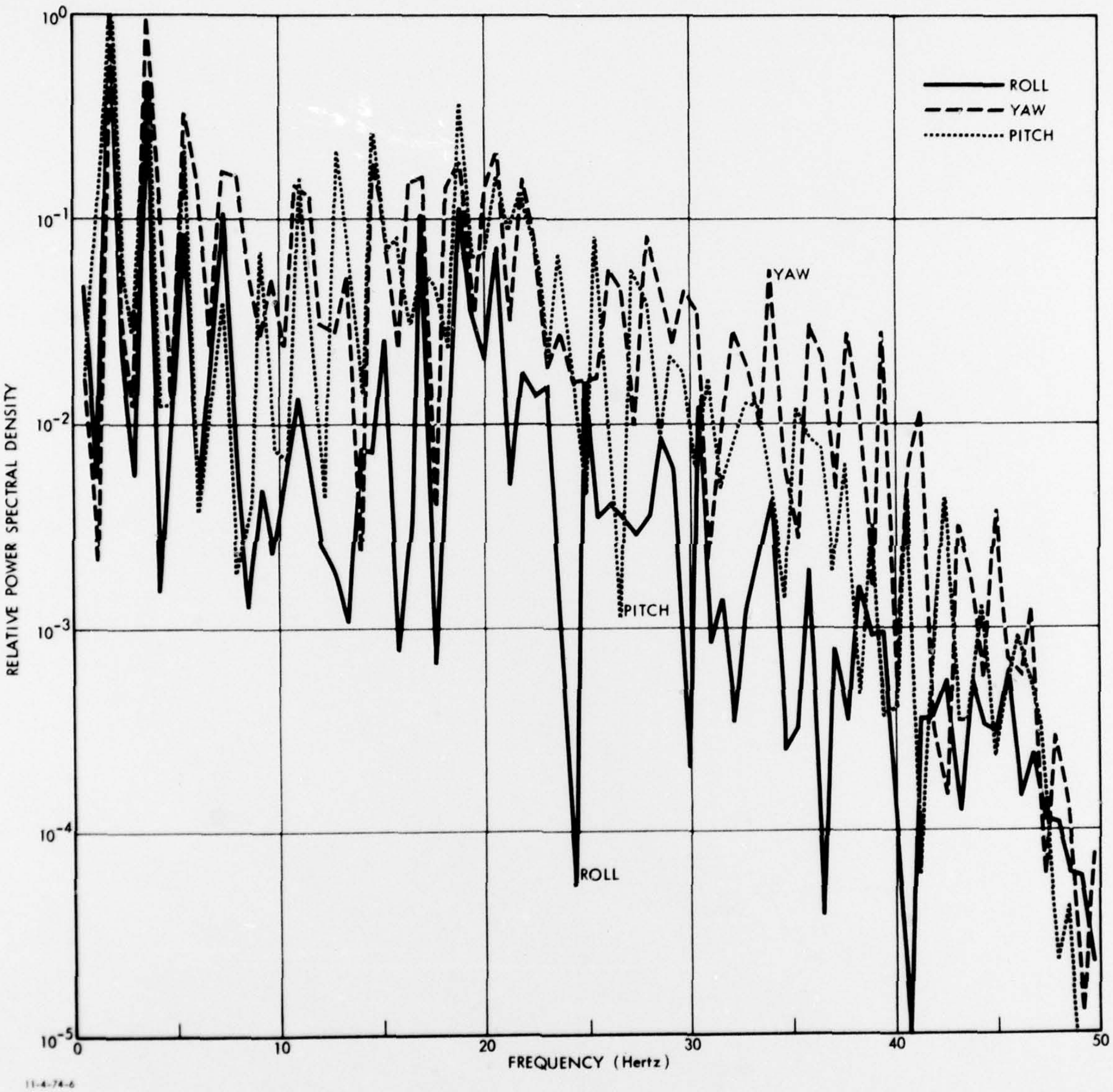

Figure 5. Spectral Density for the S-60

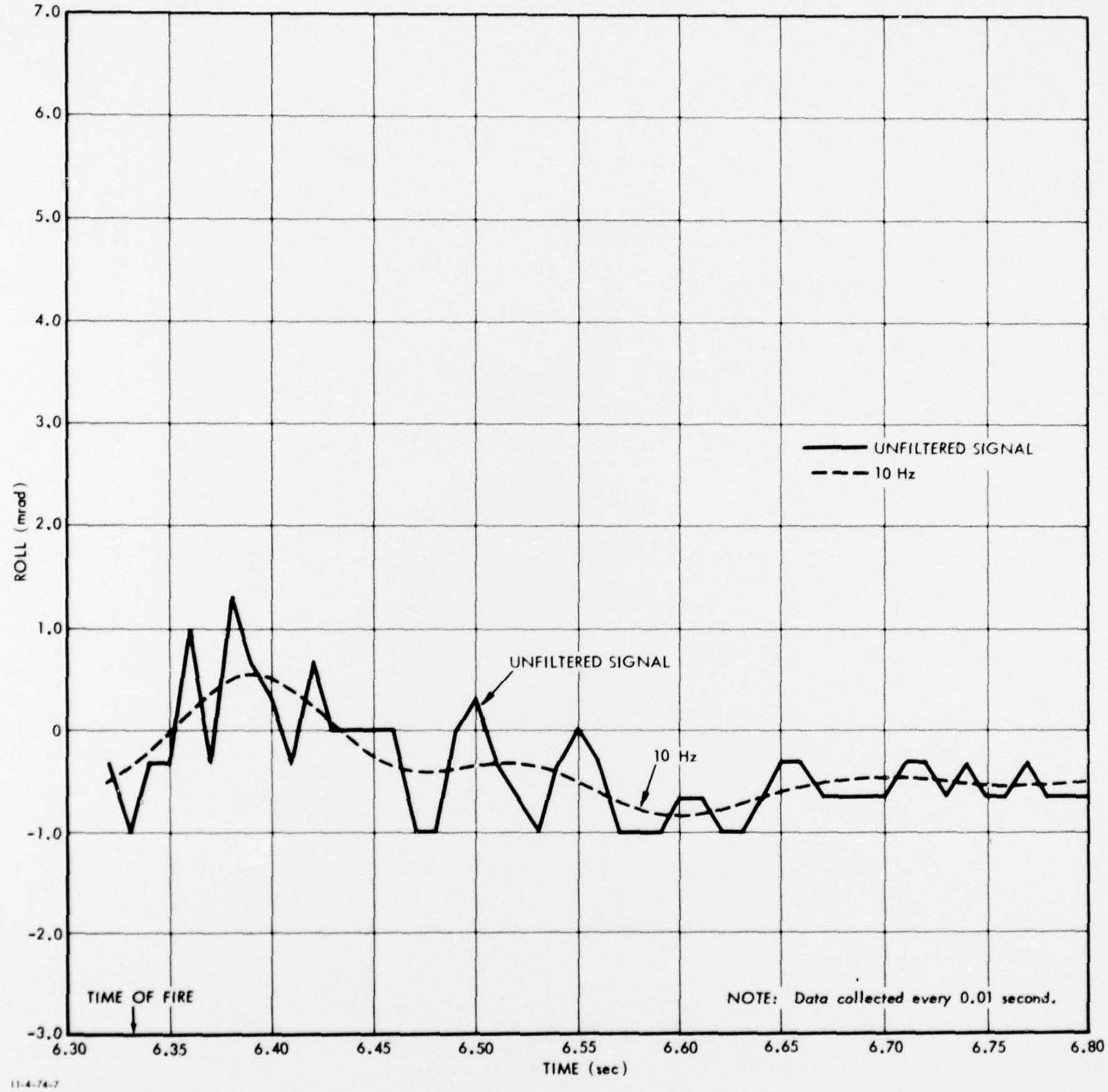

Figure 6. S-60 Roll Data at 10-Hz Cutoff Frequency

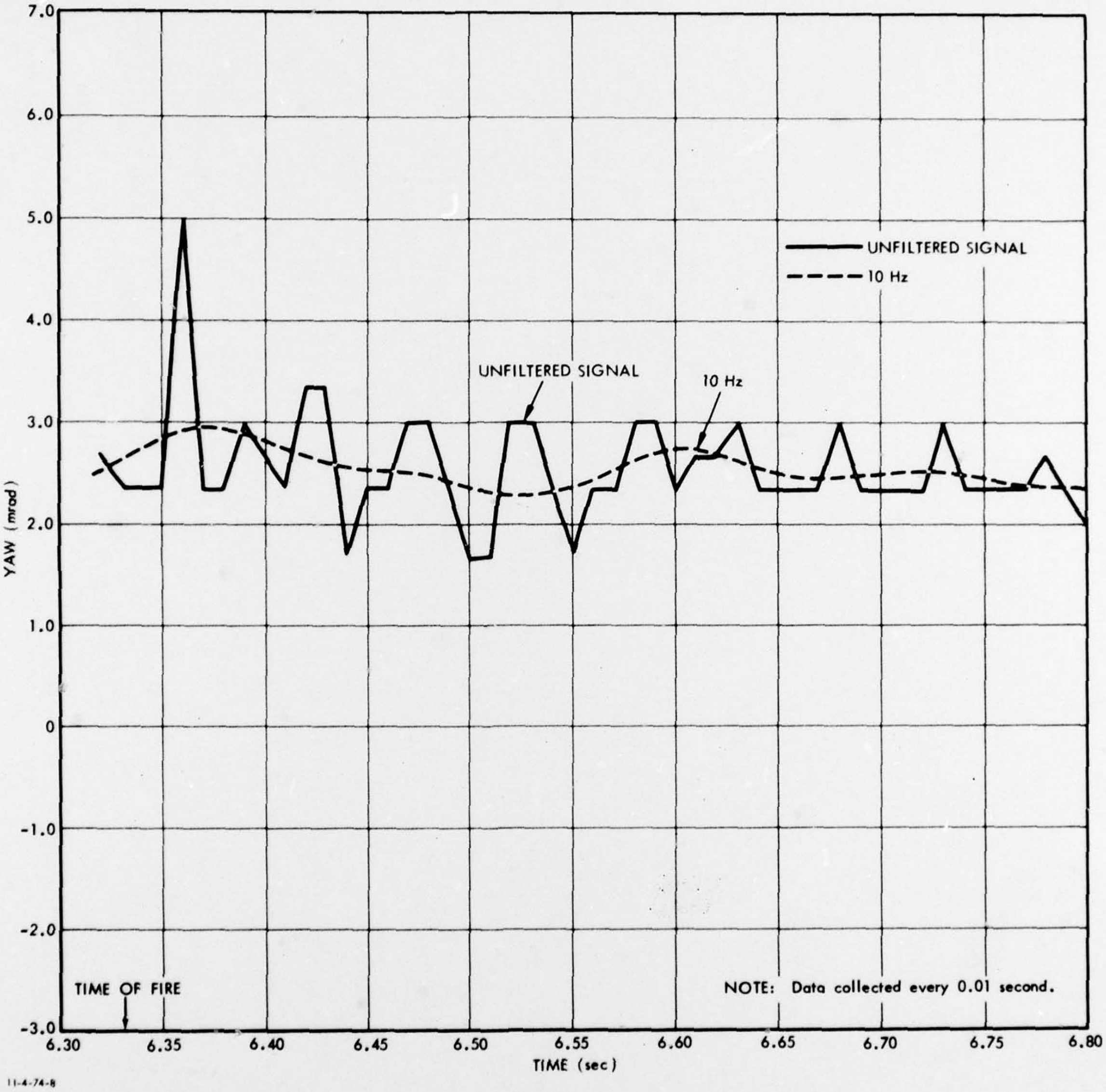

Figure 7. S-60 Yaw Data at 10-Hz Cutoff Frequency

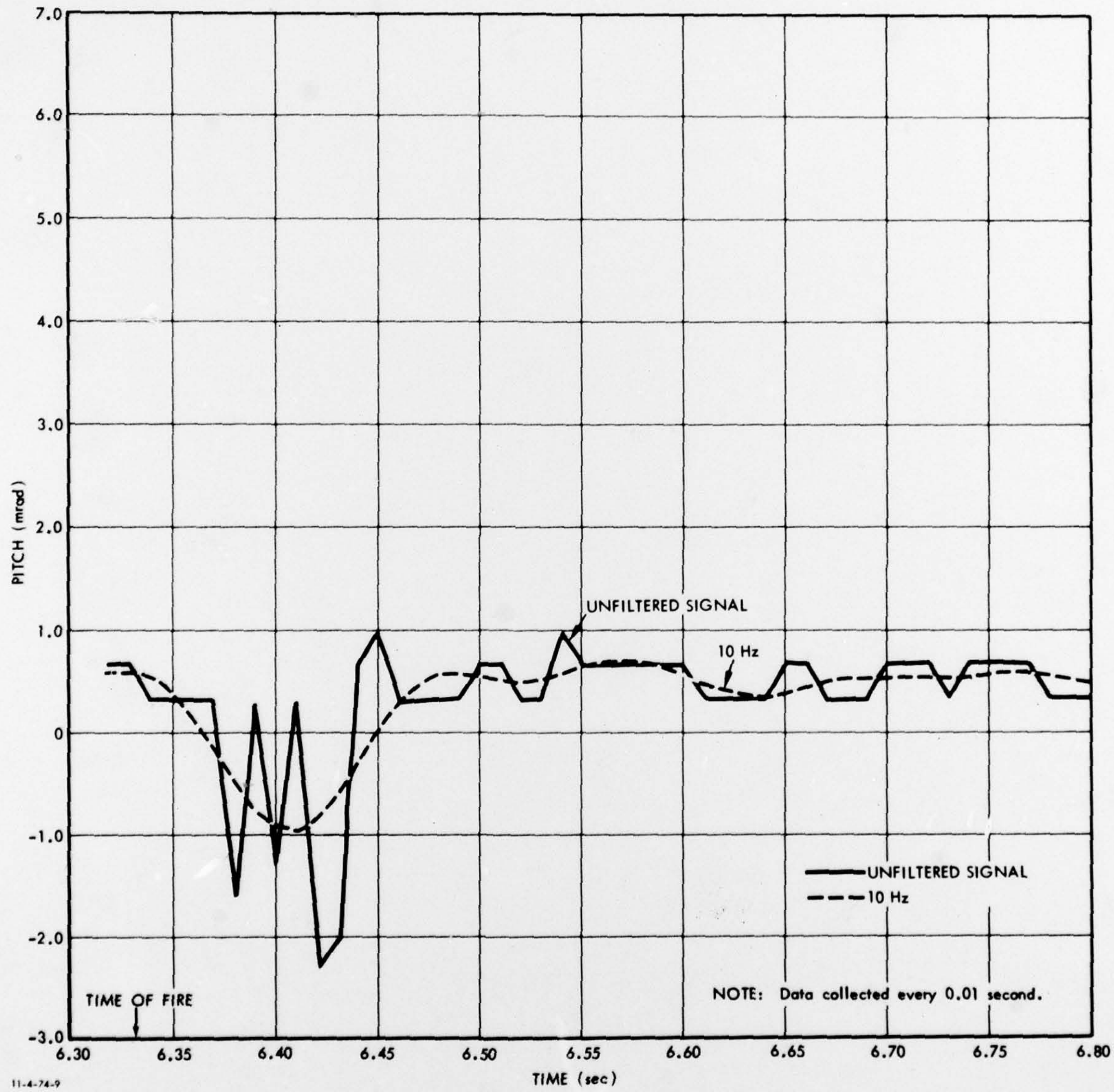

Figure 8. S-60 Pitch Data at 10-Hz Cutoff Frequency

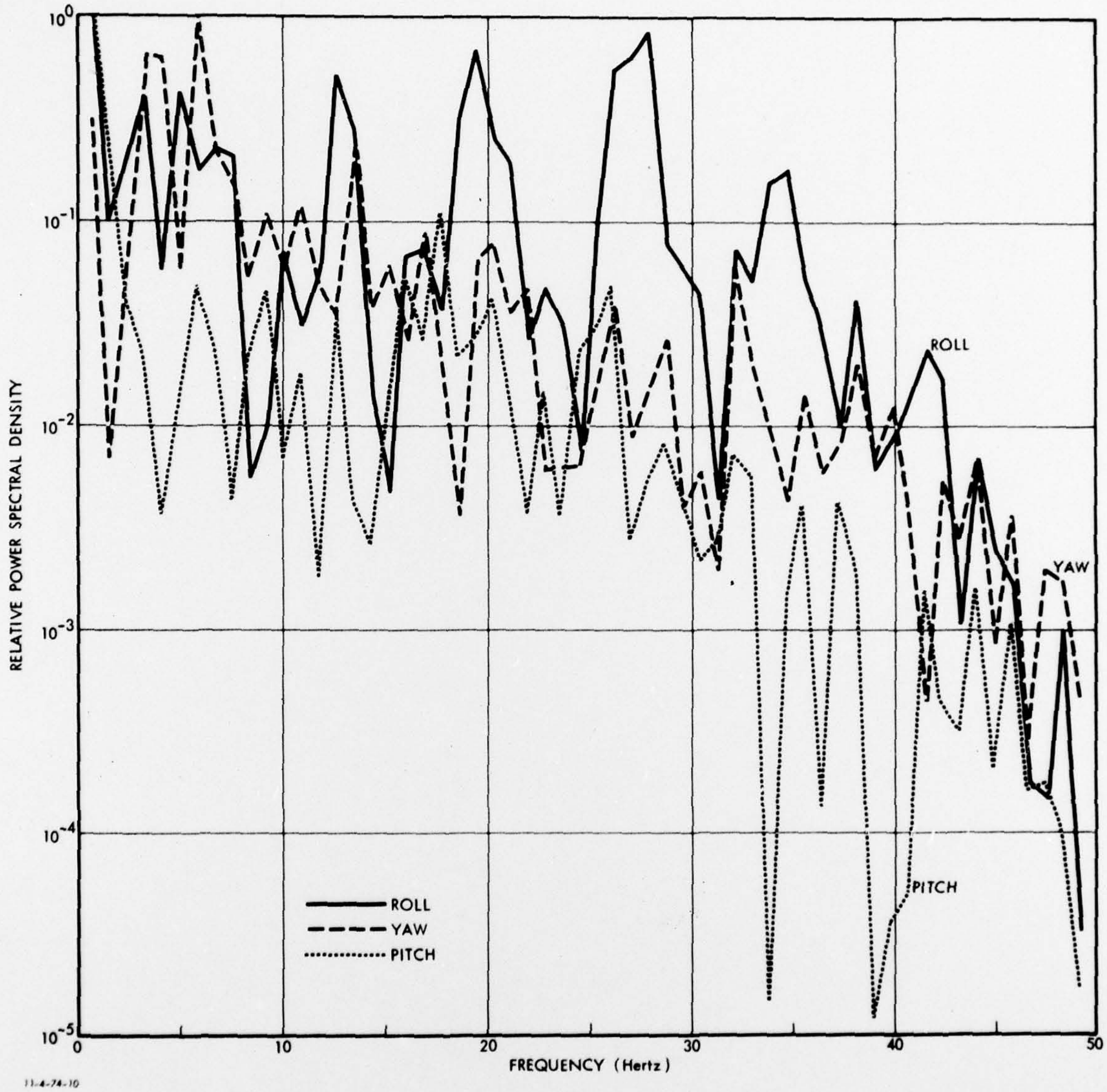

Figure 9. Spectral Density for the 5PFZ-B

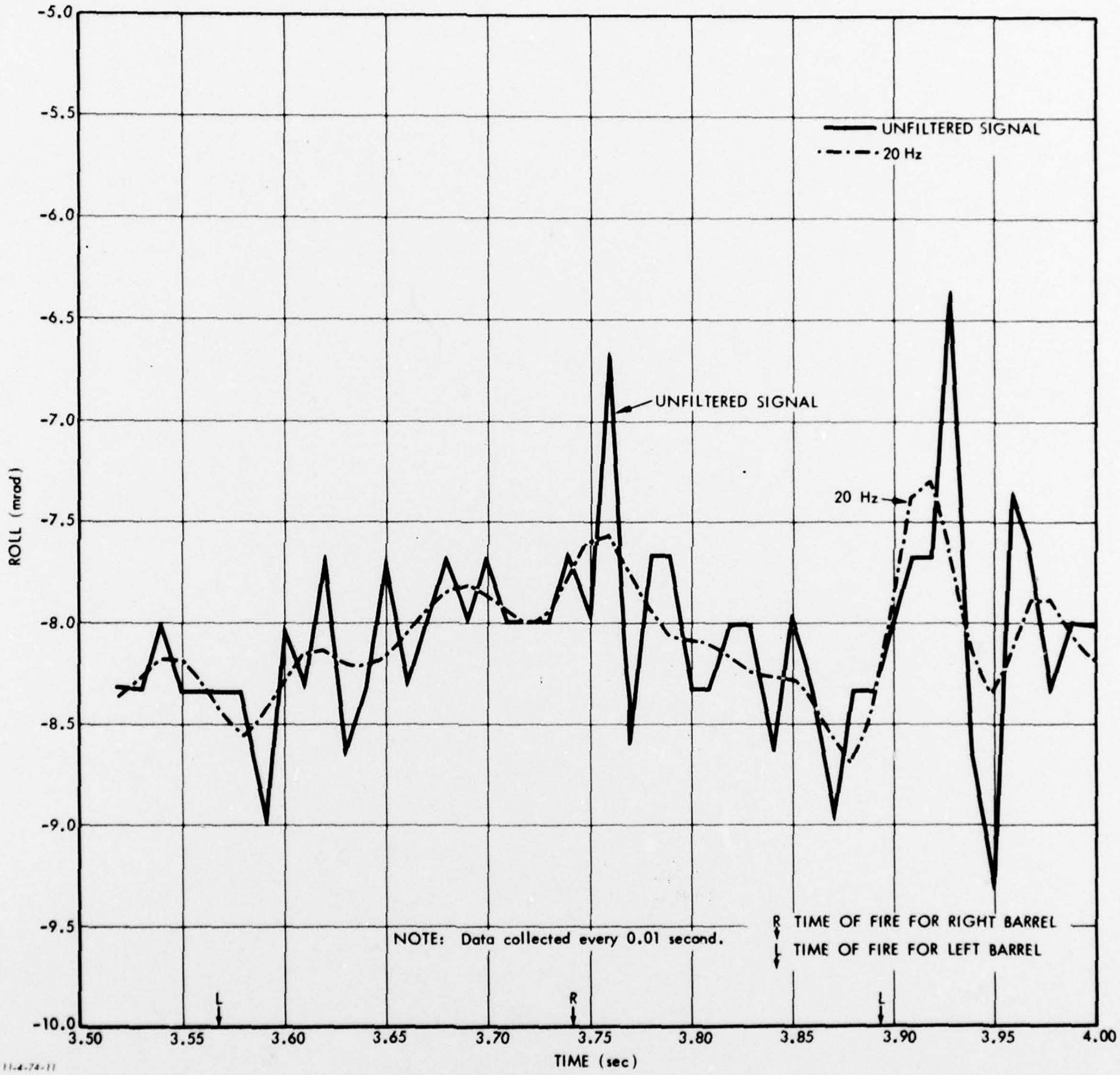

Figure 10. 5PFZ-B Roll Data at 20-Hz Cutoff Frequency

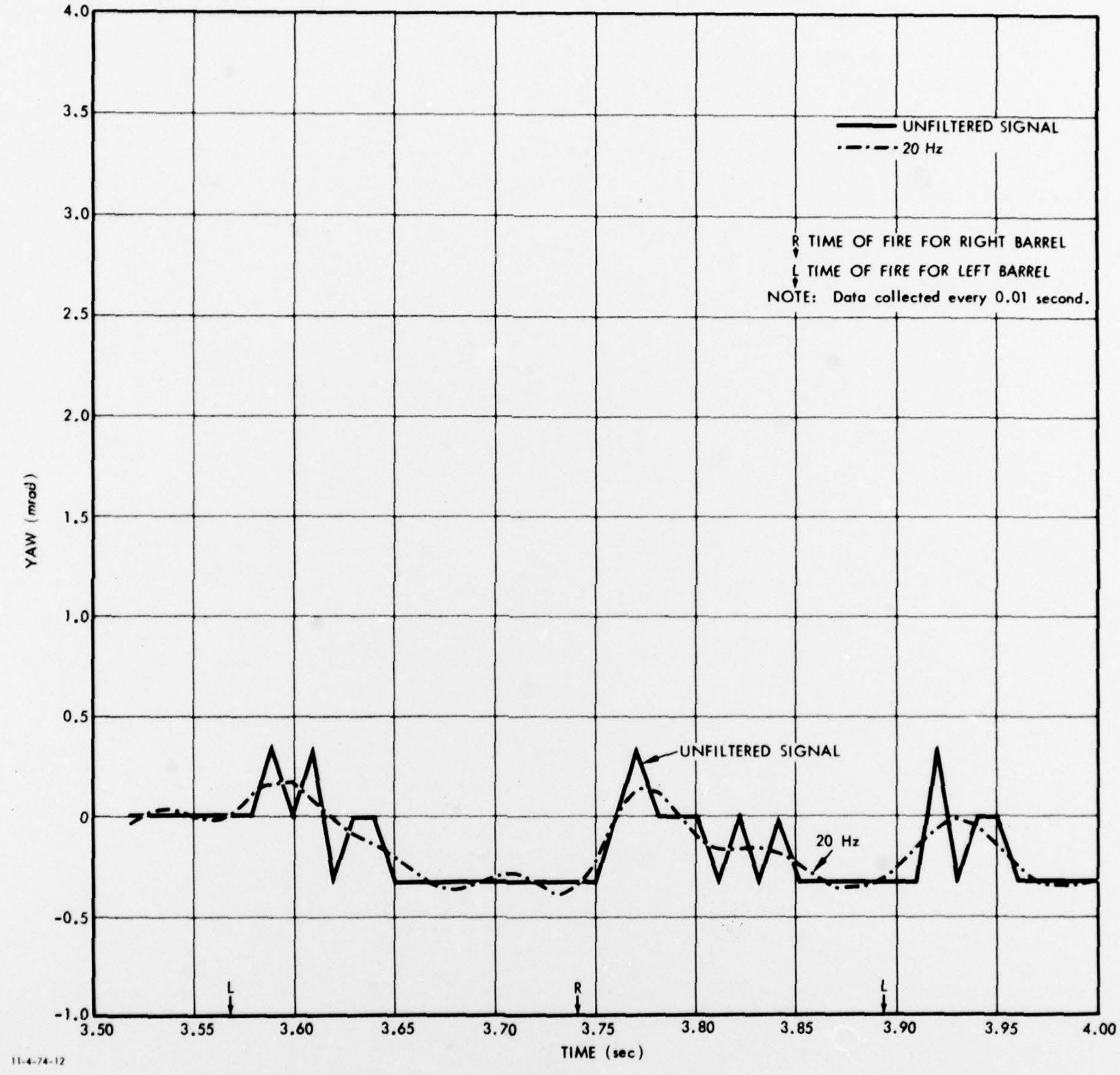

Figure 11. 5PFZ-B Yaw Data at 20-Hz Cutoff Frequency

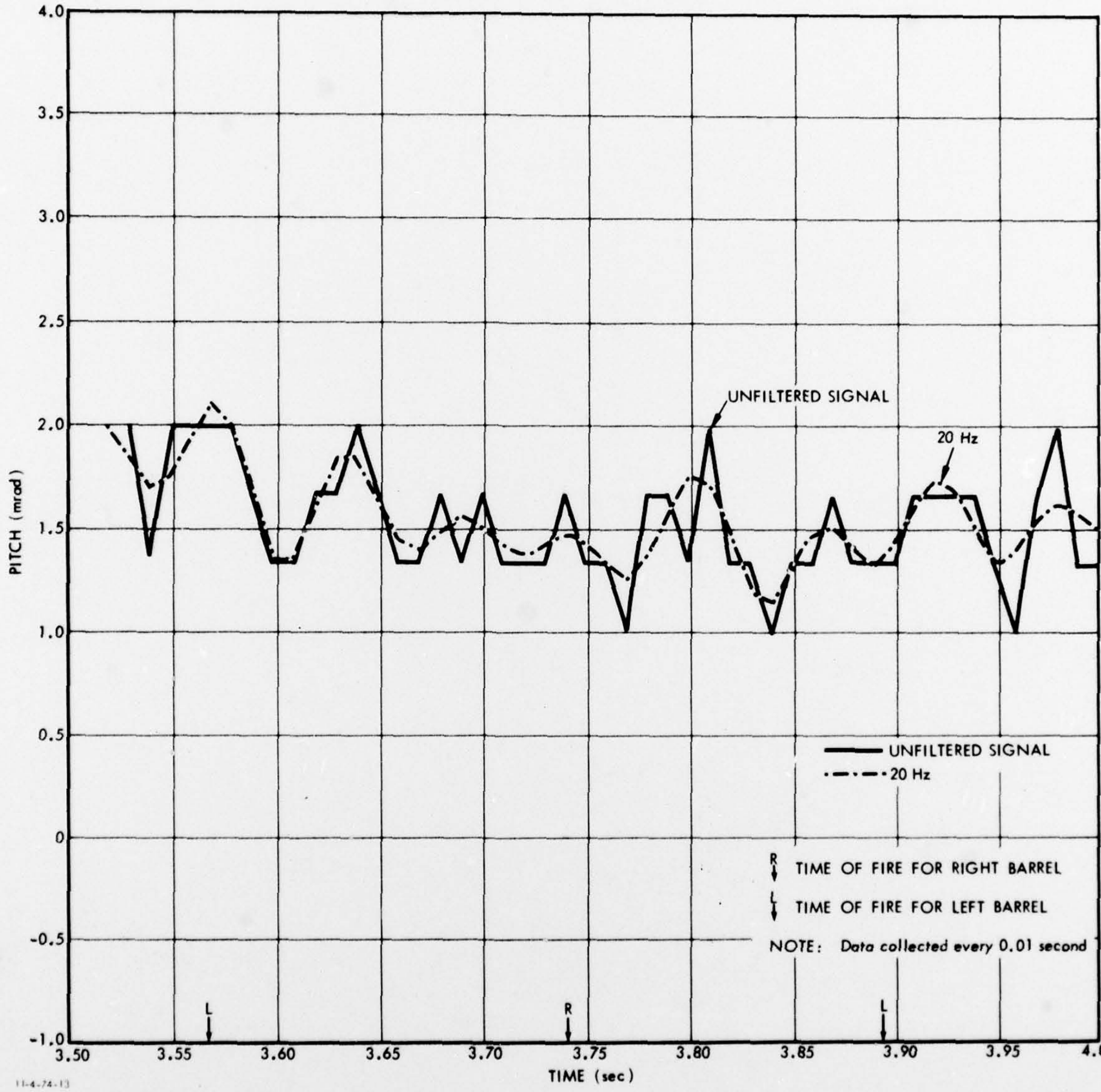

Figure 12. 5PFZ-B Pitch Data at 20-Hz Cutoff Frequency

APPENDIX

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The filters used in this analysis were low-pass filters designed to be completely transparent below the cutoff frequency, and completely opaque above it. In practice, of course, the frequency response is not exactly constant above or below the cutoff frequency, nor does the gain drop instantaneously from one to zero at cutoff. The response of the 30-Hz cutoff filter actually used is shown in the list below.

Frequency (Hz)	*Gain*	*Frequency (Hz)*	*Gain*
0	1.000	26	1.044
1	1.036	27	1.027
2	1.041	28	1.011
3	1.001	29	1.027
4	1.031	30	0.754
5	1.046	31	0.243
6	1.003	32	–0.005
7	1.025	33	0.015
8	1.049	34	–0.005
9	1.006	35	–0.015
10	1.019	36	0.023
11	1.050	37	–0.007
12	1.010	38	–0.017
13	1.013	39	0.023
14	1.051	40	–0.004
15	1.015	41	–0.020
16	1.009	42	0.022
17	1.050	43	0.001
18	1.020	44	–0.023
19	1.006	45	0.019
20	1.048	46	0.006
21	1.025	47	–0.025
22	1.003	48	0.016
23	1.046	49	0.011
24	1.028	50	–0.025
25	1.003		

The frequency response behavior of the other filters is similar, except, of course, that the cutoff frequencies are 10 and 20 Hz. In all cases the ripple (i.e., the variation in the gain above or below cutoff) is about 0.05, and the drop in gain from one to zero at cutoff takes place over an interval of about 2 to 3 Hz.

The technique used to construct the filters was suggested by T. R. Wilson of EG&G, Inc., Albuquerque, N.M., and is described in detail in "Window Functions in Integral Transform Processors and Digital Filters," a monograph written by H. D. Helms and appearing in *Real Time Digital Filtering and Spectrum Analysis,* Volume I (National Electronics Conference–Professional Growth in Electronics Seminar, 1970).