MEASUREMENTS OF FLUCTUATING PRESSURE ON A TALL BUILDING

by

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FLUID MECHANICS AND
WIND ENGINEERING PROGRAM

COLLEGE OF ENGINEERING

COLORADO STATE UNIVERSITY
FORT COLLINS, COLORADO

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for

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1. INTRODUCTION

The characteristics of fluctuating pressures on buildings have wide implications for the performance of structures and, in particular, of curtainwall systems. This project involved the gathering of a limited set of fluctuating pressure data on a model building in a boundary-layer wind tunnel in a modeled atmospheric wind to serve as a data base for research use by the Center for Building Technology at the National Bureau of Standards. Digital records were obtained of fluctuating pressure on the exterior surface of a tall building with square cross section.

2. EXPERIMENT

The measurements were performed in the Environmental wind tunnel, Figure 1, in the Fluid Dynamics and Diffusion Laboratory at Colorado State University. The model building was placed at the center of the downstream turntable. The area upstream from the model was covered with roughness elements to simulate a suburban area or city outskirt area. Spires and a barrier were placed at the wind tunnel entrance to provide a deeper boundary layer than would otherwise be available.

The model building, Figure 2, was 20 inches high and 5 inches wide in each horizontal dimension. One face, arbitrarily designated the north face, contained 6 taps for pressure measurement as shown in Figure 2. Other taps existed in this building, but they were sealed for this test. The building was placed at the turntable center so that no rough ness elements were closer than 2 ft from the model, Figure 3. This ensured that individual roughness element wakes were not involved in local flow characteristics about the building. A pitot-static probe was installed on the wind tunnel centerline 2 ft upwind of the model at the height of the model. The approach velocity and longitudinal turbulence intensity profiles, measured several feet upwind of the model, are shown in Figure 4.

The pressure instrumentation is shown in schematic form in Figure 5. Pressure taps (1/16 in. diameter) on the model were connected to Setra model 237 differential pressure transducers with less than 2 inches of tubing. Thus, the frequency response of the transducer cavity/tube was flat to at least 800 Hz. The reference side of the transducer was connected to the static side of the pitot-static tube through a long tube. No attempt was made to determine the frequency response of the transducer-cavity/tube/static-probe combination or to measure the fluctuations in tunnel static pressure directly.

Output from the Setra transducer was split and was passed through three identical Wavetek model 352 lowpass filters. Cutoff frequencies were set at 800, 100 and 50 Hz for channels labeled F1, F2 and F3 respectively.

Amplitude and phase characteristics of the filters are shown in Figures 6 and 7 which were extracted directly from the filter user manual. Attenuation at the cutoff frequency was -3db with a 48 db/octave rolloff rate. It can be shown that a phase shift linear with frequency, Figure 7, produces a time delay without other distortion to the signal. Thus, a time shift should be apparent between the three time series channels due to the linear phase shift in the filters.

The differential pressure from the pitot-static probe representing approach velocity at building height was measured by a Statham model PM283 differential pressure transducer. No attempt was made to obtain a high frequency response from this transducer. The output of this transducer was also recorded as a fourth data channel.

With the approach wind in the wind tunnel at the building height set at about 30 fps, data were recorded digitally on all four data channels at a sample rate of 1563 samples per second. Data acquisition was controlled by the laboratory computer: a HP 21MX-E minicomputer with Preston Scientific A/D converter. The A/D converter has a simultaneous sample and hold at the front end so that no time shifts in the data acquisition occur due to the A/D conversion process. The digitized data were temporarily stored on disk and finally transferred to digital tape.

As the data were transferred to tape, the three pressure channels were divided by the velocity channel to form time series of dimensionless pressure coefficient:

$$C_p = \frac{P - P_s}{q}$$

P = local tap pressure

P_s = tunnel static pressure

$q = 0.5 \rho U_R^2$

The fourth velocity channel was recorded on tape with engineering units of psf representing the pitot-static tube dynamic pressure. Data format for the digital tape was:

nine track
unlabeled
ASCII format
1600 bpi
block size - see Table 1

Data processing onto digital tape was performed so that all values on tape are in ASCII as explained in Table 1. Table 1 also identifies experimental run numbers with experimental data.

Data were acquired for each of the six tap locations for the following wind directions: 0, 20, 40, 60, 75, 80, 85, 90, 110, 130, 150, and 180 degrees. A zero wind direction is perpendicular to the north face. A 90 degree wind approaches normal to the east face. Data were recorded for 35 seconds at 1563 samples per second.

3. DATA CHARACTERISTICS

After processing onto digital tape, data were recalled so that a few characteristics of the data could be determined. Table 2 shows a sample of data retrieved from tape. Figure 8 shows spectra from one data run to observe the filter attenuation. The attenuations at 50 and 100 Hz can clearly be seen. The nyquist frequency of 780 Hz prevents the cutoff at 800 Hz from being observed.

Time series traces from the same data run with three filters are shown in Figures 9 and 10. The time shift due to filter phase characteristics is clearly seen.

Figure 11 shows the variation of C_p mean, rms, maximum and minimum for each tap for each wind direction measured. Figure 12 shows C_p rms on an expanded scale. The influence of the various filters can be seen in these two figures.

TABLES

Table 1

```
C
C              DETAILED DESCRITION OF ASCII DATA TAPE
C
C     FOR EACH RUN:
C        1ST RECORD - IRUN,NCHAN,IWIND,SAMPL,RATE,PREF,RHO,WVEL
C            FORMAT - 2I3,I4,2F9.2,3F8.4
C        2ND --> (NCHAN+1) RECORDS - ICHAN,LABEL,SMEAN,SRMS
C                          FORMAT  - I2,2X,A2,2F8.4
C        (NCHAN+2) --> EOF RECORDS - (CP(I,J) I=1,NCHAN J=1,NVAR)
C                          FORMAT  - 16F8.4
C
C        IRUN    -   RUN NUMBER
C        NCHAN   -   NUMBER OF DATA CHANNELS
C        IWIND   -   WIND DIRECTION
C        SAMPL   -   NUMBER OF DATA POINTS PER CHANNEL
C        RATE    -   SAMPLES PER SECOND PER CHANNEL
C        PREF    -   REFERENCE PRESSURE IN PSF
C        RHO     -   AIR DENSITY IN LB*SEC**2/FT**4
C        WVEL    -   TUNNEL WIND VELOCITY IN FT/SEC
C        ICHAN   -   CHANNEL NUMBER
C        LABEL   -   'CP', PRESSURE COEFFICIENT   'PR', PRESSURE
C        SMEAN   -   CHANNEL TOTAL CALCULATED MEAN
C        SRMS    -   CHANNEL TOTAL CALCULATED RMS
C        CP(NCHAN,NVAR)  -   PRESSURE OR PRESSURE COEFFICIENTS
C                            WHERE NVAR = 16 / NCHAN
C
C        AN END-OF-FILE MARK IS PUT ON AFTER EVERY RUN.
C        AN EXTRA END-OF-FILE MARK IS PUT ON AFTER THE LAST RUN PER TAPE
C
       EACH RUN NUMBER HAS FOUR CHANNELS OF DATA ASSOCIATED WITH IT,
          1,2,3,4, AND EACH CHANNEL IS A SEPARATE DATA FILE ON THE TAPE
       THERE ARE SIX DATA TAPS ON THE TAPE, EACH HAVING WIND DIRECTIONS
         0, 20, 40, 60, 75, 80, 85, 90, 110, 130, 150,   AND 180
 TAP #\ RUN # ASSOCIATED WITH WIND DIRECTION
   1    43, 44, 45, 46, 11, 12, 13, 14,  15,  16,  17,  AND  18
   2    30, 29, 28, 27, 26, 25, 24, 23,  22,  21,  20,  AND  19
   3    31, 32, 33, 34, 35, 36, 37, 38,  39,  40,  41,  AND  42
   4    47, 48, 49, 50, 51, 52, 53, 54,  55,  56,  57,  AND  58
   5    70, 69, 68, 67, 66, 65, 64, 63,  62,  61,  60,  AND  59
   6    72, 73, 74, 75, 76, 77, 78, 79,  80,  81,  82,  AND  83
```

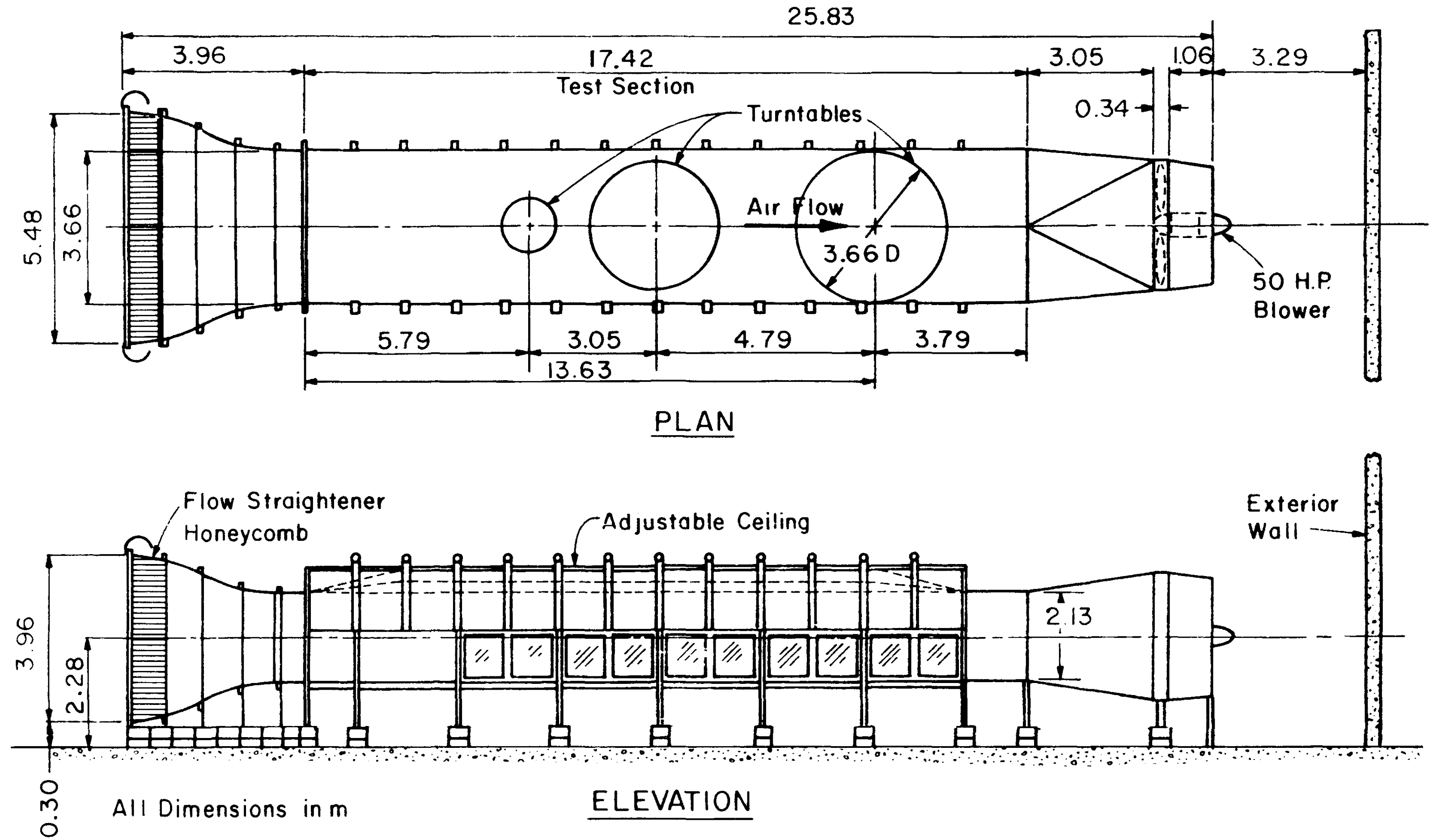
Table 2

Data Printout - Tape 1

```
43   4     0 32768 00   1562 50      8653     0019 30 1798
1   CP   .3584     .1915
2   CP   .3512     .1723
3   CP   .3507     .1668
4   PR   .8653     .0460
```

.2184	.1858	.2057	.8821	.1878	.1778	.1945	.8870	.1750	.1729	.1864	.8870	.2120	.1697	.1800	.8870
.2442	.1697	.1752	.8821	.2345	.1713	.1703	.8821	.1846	.1746	.1703	.8821	.2216	.1810	.1703	.8821
.2088	.1858	.1703	.8821	.1605	.1890	.1703	.8821	.1540	.1971	.1768	.8772	.1347	.2019	.1800	.8870
.0591	.2084	.1848	.8870	.0591	.2100	.1880	.8919	.1363	.2116	.1929	.8821	.1138	.2116	.1961	.8821
.0961	.2100	.2009	.8870	.1347	.2051	.2041	.8919	.1717	.1987	.2057	.8919	.2168	.1874	.2074	.8967
.2297	.1762	.2074	.8967	.1894	.1617	.2074	.8967	.1621	.1456	.2057	.8967	.1299	.1311	.2057	.9016
.1589	.1214	.2057	.9016	.1994	.1134	.2025	.9016	.1846	.1086	.1993	.9016	.2120	.1102	.1961	.9016
.1991	.1166	.1913	.8967	.2249	.1247	.1864	.9016	.2796	.1375	.1816	.9016	.2313	.1520	.1768	.9016
.1701	.1649	.1703	.9016	.2104	.1778	.1655	.9016	.2007	.1890	.1607	.9016	.2603	.1939	.1542	.8967
.2796	.1971	.1510	.9016	.2329	.2051	.1510	.9016	.2796	.2051	.1462	.8967	.3504	.2068	.1446	.9065
.2748	.2068	.1430	.9065	.3166	.2084	.1430	.9016	.3118	.2100	.1430	.9016	.3456	.2132	.1446	.9016
.3488	.2196	.1478	.9016	.2828	.2261	.1510	.9065	.2538	.2341	.1542	.9065	.3713	.2438	.1575	.8967
.4808	.2534	.1607	.9065	.4889	.2631	.1671	.9065	.4792	.2792	.1784	.9016	.4728	.2905	.1848	.9065
.4744	.3017	.1929	.9016	.4583	.3114	.2009	.9065	.5050	.3194	.2090	.9065	.4631	.3291	.2170	.9065
.4003	.3387	.2251	.9016	.4792	.3532	.2347	.9065	.4567	.3677	.2412	.9065	.4551	.3822	.2492	.9065
.5887	.3999	.2589	.9065	.6064	.4176	.2653	.9065	.5581	.4305	.2734	.9065	.5307	.4498	.2862	.9065
.5066	.4659	.2975	.9065	.5275	.4772	.3072	.9065	.5951	.4836	.3184	.9065	.5645	.4885	.3265	.9065
.4985	.4917	.3394	.9065	.4824	.4933	.3474	.9016	.5033	.4981	.3619	.9065	.4969	.5013	.3715	.9065
.4937	.5062	.3812	.9065	.4486	.5110	.3941	.9016	.4808	.5174	.4037	.9065	.5050	.5190	.4150	.9065
.5114	.5271	.4295	.9065	.5645	.5303	.4424	.9065	.5677	.5303	.4520	.9065	.6112	.5287	.4649	.9065
.5871	.5223	.4746	.9065	.5629	.5142	.4842	.9065	.4985	.5046	.4923	.9065	.4937	.4981	.5019	.9065
.4856	.4917	.5084	.9016	.4341	.4885	.5148	.9065	.4357	.4868	.5180	.9114	.5114	.4917	.5229	.9065
.5339	.4949	.5229	.9065	.5484	.5029	.5277	.9065	.5484	.5174	.5293	.9114	.4744	.5255	.5309	.9114
.3681	.5319	.5293	.9114	.3810	.5351	.5293	.9065	.3907	.5319	.5277	.9065	.4534	.5271	.5245	.9065
.5001	.5174	.5229	.9163	.5146	.5079	.5196	.9065	.4695	.4933	.5149	.9065	.4438	.4820	.5132	.9065
.4019	.4691	.5100	.9065	.3746	.4563	.5052	.9065	.4069	.4450	.5019	.9016	.4502	.4402	.5035	.9016
.5436	.4353	.5003	.9016	.5581	.4337	.4987	.9016	.5693	.4321	.4971	.9065	.4953	.4321	.4939	.9016
.4760	.4337	.4923	.8967	.5259	.4353	.4891	.8967	.5758	.4386	.4874	.8967	.5726	.4418	.4842	.9016
.5838	.4450	.4794	.9016	.5999	.4514	.4778	.9016	.5983	.4563	.4730	.9016	.5887	.4611	.4681	.8919
.6209	.4756	.4681	.9016	.5822	.4869	.4665	.8967	.5963	.4987	.4673	.8967	.6402	.5126	.4601	.8967
.6337	.5271	.4585	.8967	.7255	.5400	.4557	.8967	.7931	.5528	.4553	.8919	.7625	.5641	.4520	.8870
.6450	.5754	.4536	.8870	.5710	.5850	.4536	.8870	.5854	.5931	.4553	.8870	.5838	.6011	.4585	.8870
.6096	.6076	.4601	.8870	.5822	.6205	.4714	.8919	.6160	.6285	.4794	.8870	.5693	.6382	.4874	.8870
.5050	.6462	.4971	.8870	.5227	.6526	.5068	.8870	.4631	.6559	.5180	.8870	.3955	.6543	.5309	.8821
.4647	.6494	.5422	.8870	.4422	.6398	.5534	.8821	.3456	.6269	.5663	.8821	.4212	.6092	.5776	.8870
.5389	.5883	.5389	.8821	.5098	.5641	.5985	.8870	.4856	.5400	.6098	.8870	.4583	.5190	.6194	.8821
.4100	.4965	.6275	.8870	.4406	.4756	.6323	.8821	.4422	.4579	.6372	.8772	.4068	.4434	.6388	.8772
.3649	.4337	.6372	.8821	.3601	.4273	.6355	.8821	.3858	.4257	.6307	.8821	.3247	.4257	.6227	.8772
.3713	.4289	.6146	.8772	.3842	.4321	.6017	.8821	.3488	.4337	.5889	.8821	.3730	.4337	.5744	.8821
.4084	.4369	.5631	.8821	.3891	.4321	.5486	.8821	.3649	.4241	.5309	.8821	.3392	.4128	.5148	.8821
.3456	.3999	.4987	.8821	.3681	.3854	.4826	.8772	.3874	.3709	.4649	.8772	.3730	.3613	.4520	.8821
.3520	.3516	.4359	.8821	.3536	.3452	.4231	.8772	.3649	.3436	.4118	.8772	.3552	.3436	.4005	.8772
.3569	.3436	.3833	.8772	.3327	.3516	.3860	.8821	.2635	.3565	.3796	.8772	.2281	.3613	.3748	.8772
.2007	.3645	.3699	.8772	.1492	.3661	.3683	.8723	.1234	.3661	.3651	.8821	.1653	.3645	.3635	.8772
.0896	.3581	.3619	.8723	.1122	.3500	.3635	.8772	.1508	.3387	.3619	.8723	.1766	.3243	.3619	.8772
.1927	.3049	.3603	.8723	.1444	.2808	.3587	.8723	.1202	.2550	.3603	.8772	.1331	.2325	.3603	.8723
.1911	.2068	.3587	.8723	.1669	.1810	.3571	.8723	.1569	.1585	.3522	.8772	.1331	.1408	.3490	.8723
.0784	.1263	.3410	.8723	.1041	.1182	.3345	.8674	.1573	.1150	.3249	.8723	.1830	.1182	.3168	.8772
.1379	.1247	.3023	.8772	.1573	.1327	.2895	.8772	.2007	.1391	.2750	.8723	.1331	.1456	.2605	.8772
.1975	.1536	.2492	.8723	.2023	.1585	.2347	.8772	.1878	.1585	.2202	.8772	.1685	.1568	.2041	.8674

FIGURES



ENVIRONMENTAL WIND TUNNEL
FLUID DYNAMICS & DIFFUSION LABORATORY
COLORADO STATE UNIVERSITY

Figure 1. Wind Tunnel Configuration

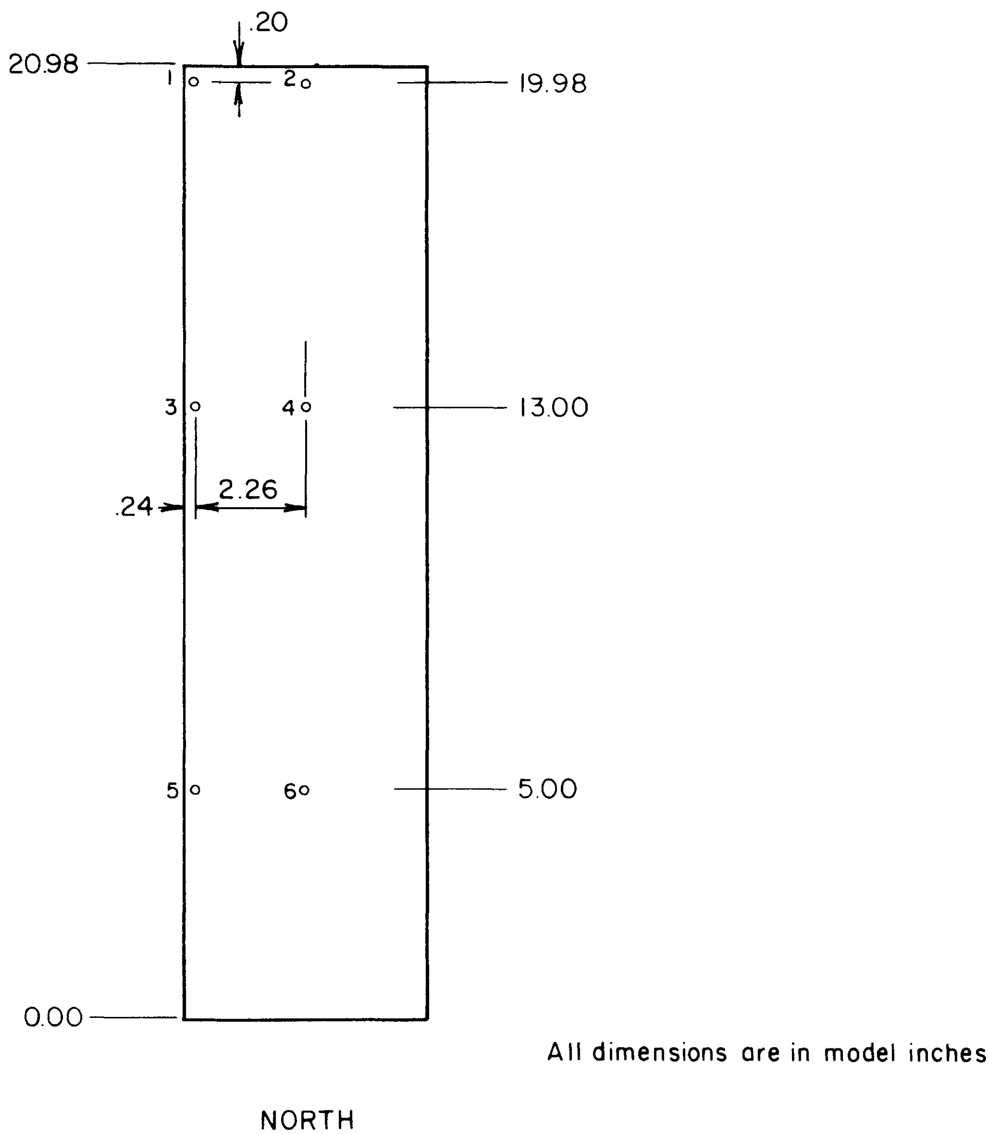


Figure 2. Model Building

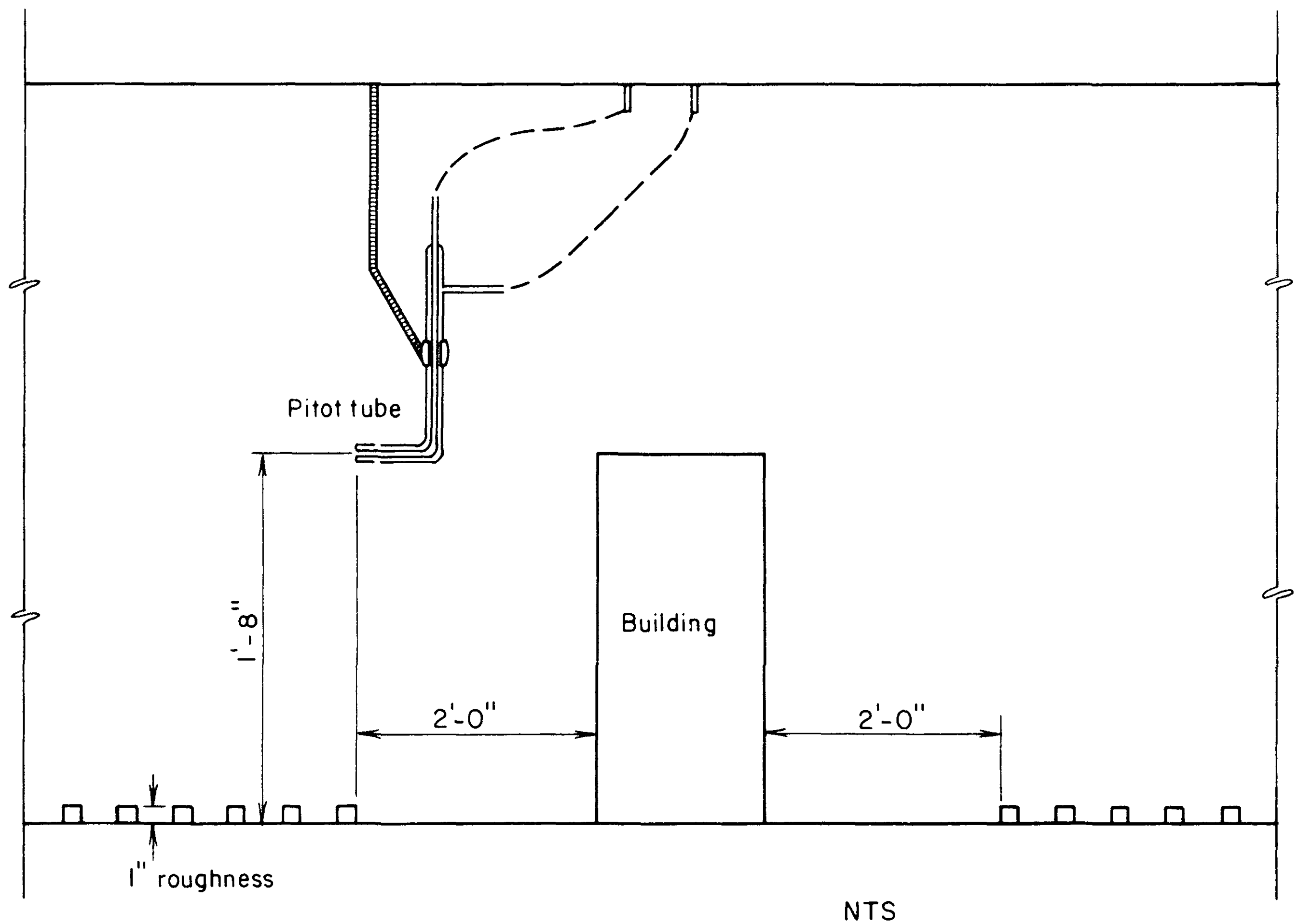


Figure 3. Model Placement

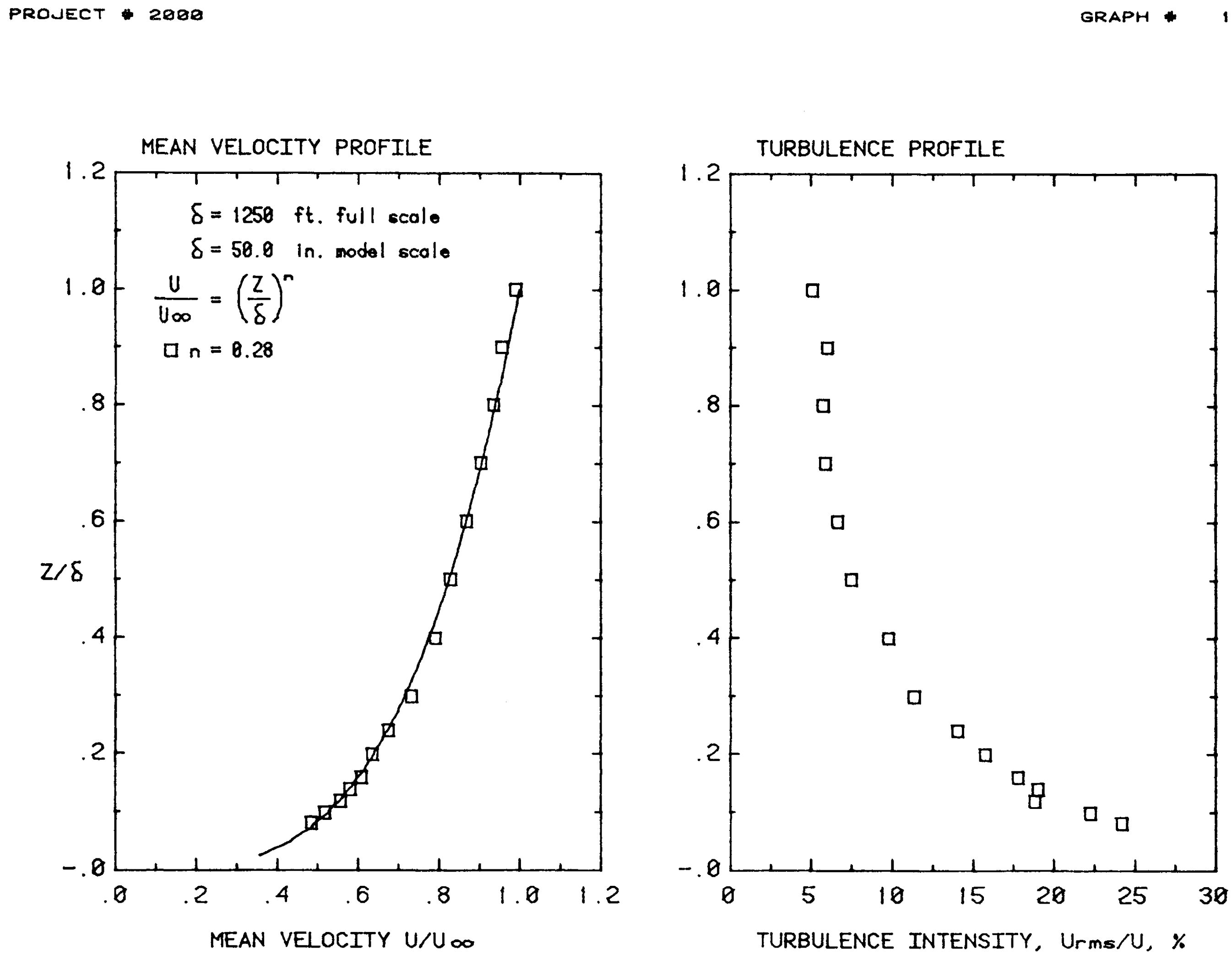


Figure 4. Mean Velocity and Turbulence Profiles Approaching the Model

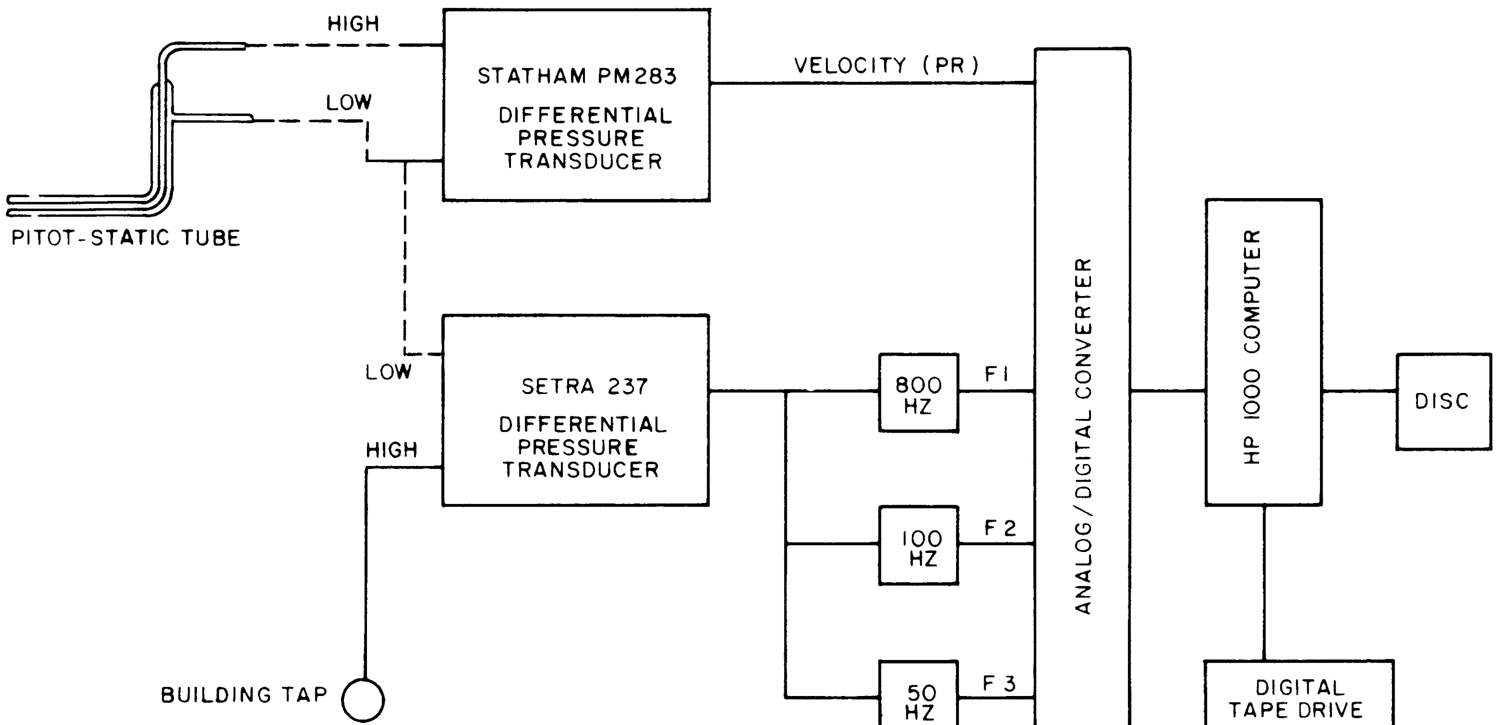


Figure 5. Schematic Diagram of Instrumentation

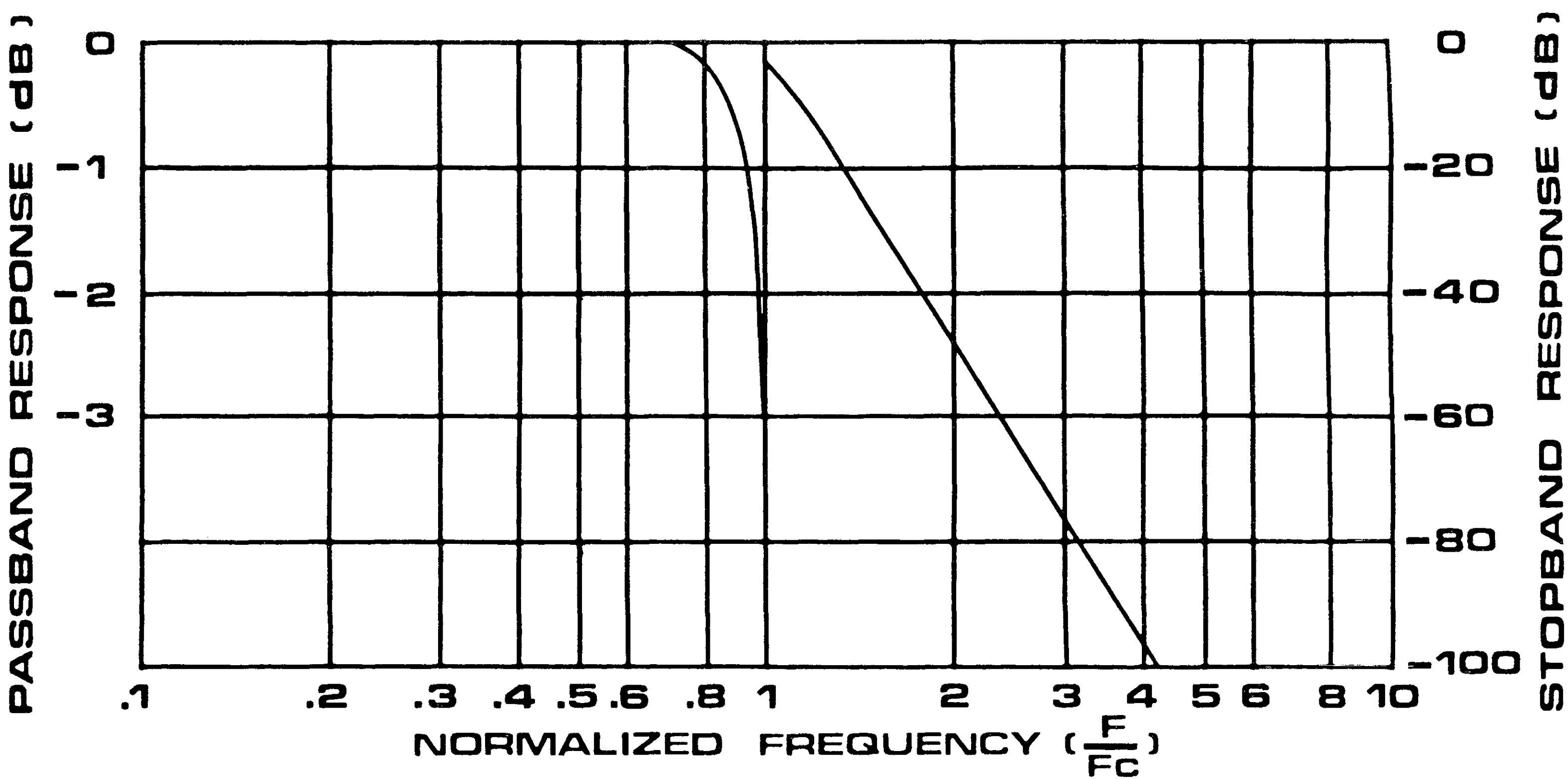


Fig. 2-5 852 Flat Ampl. Response - Lo Pass

Figure 6. Filter Amplitude Characteristics

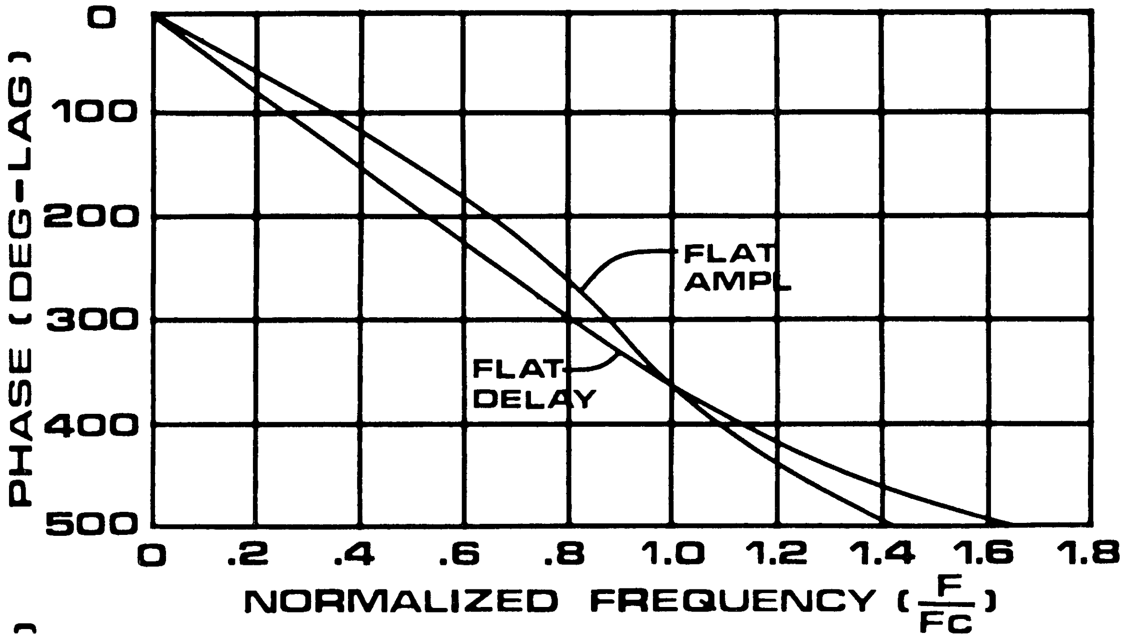


Fig. 2-9 852 Phase Response - Lo Pass

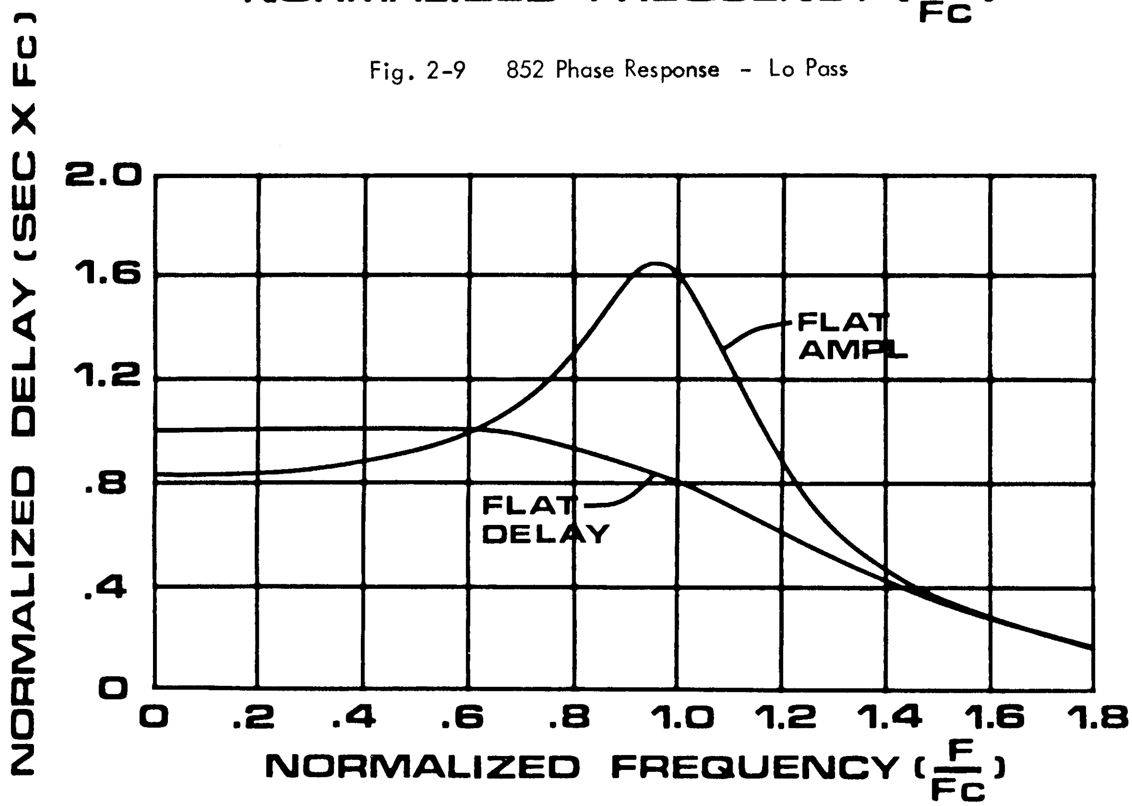


Fig. 2-10 852 Delay Response - Lo Pass

Figure 7. Filter Phase Characteristics

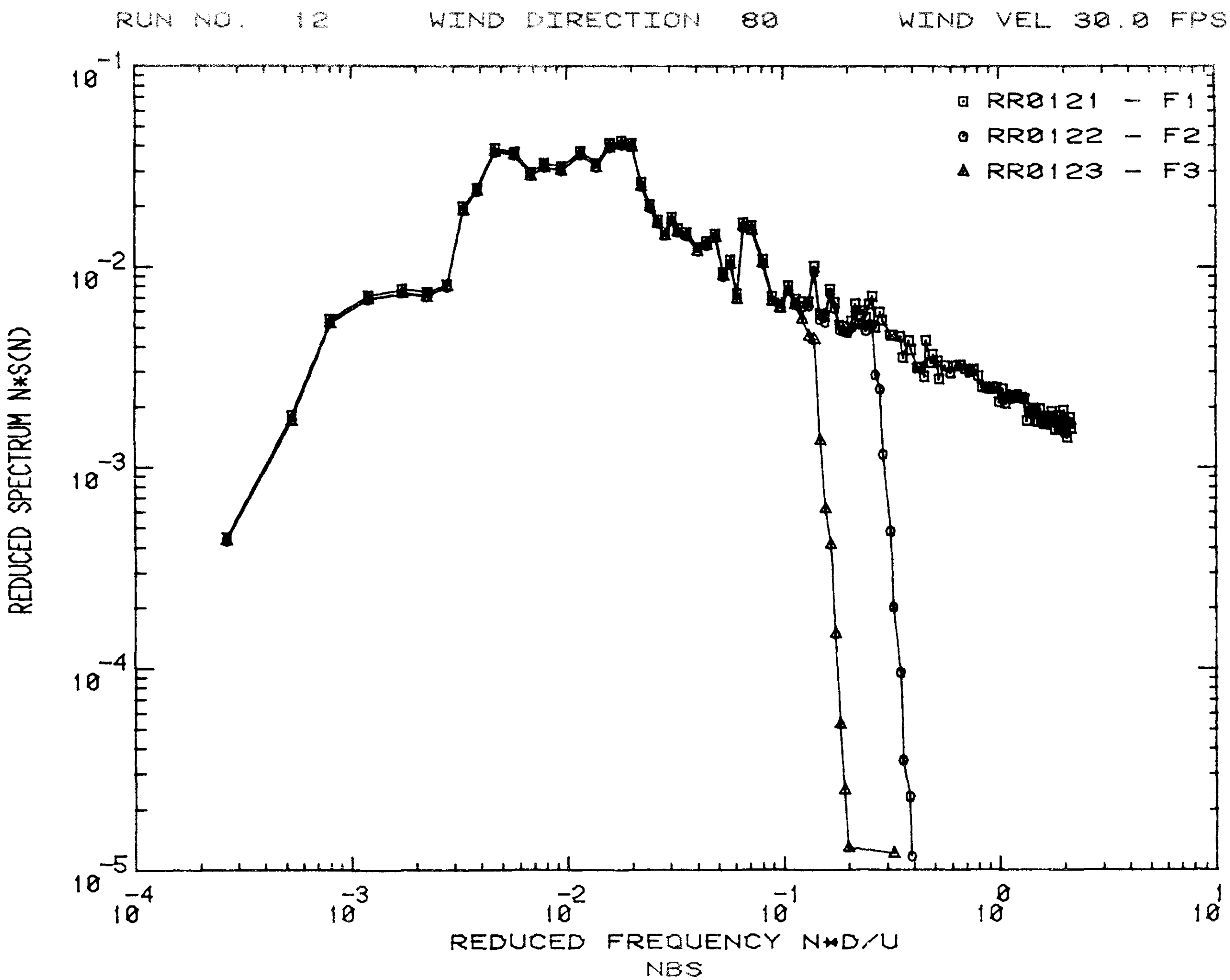


Figure 8. Spectra for One Data Run with Three Filters

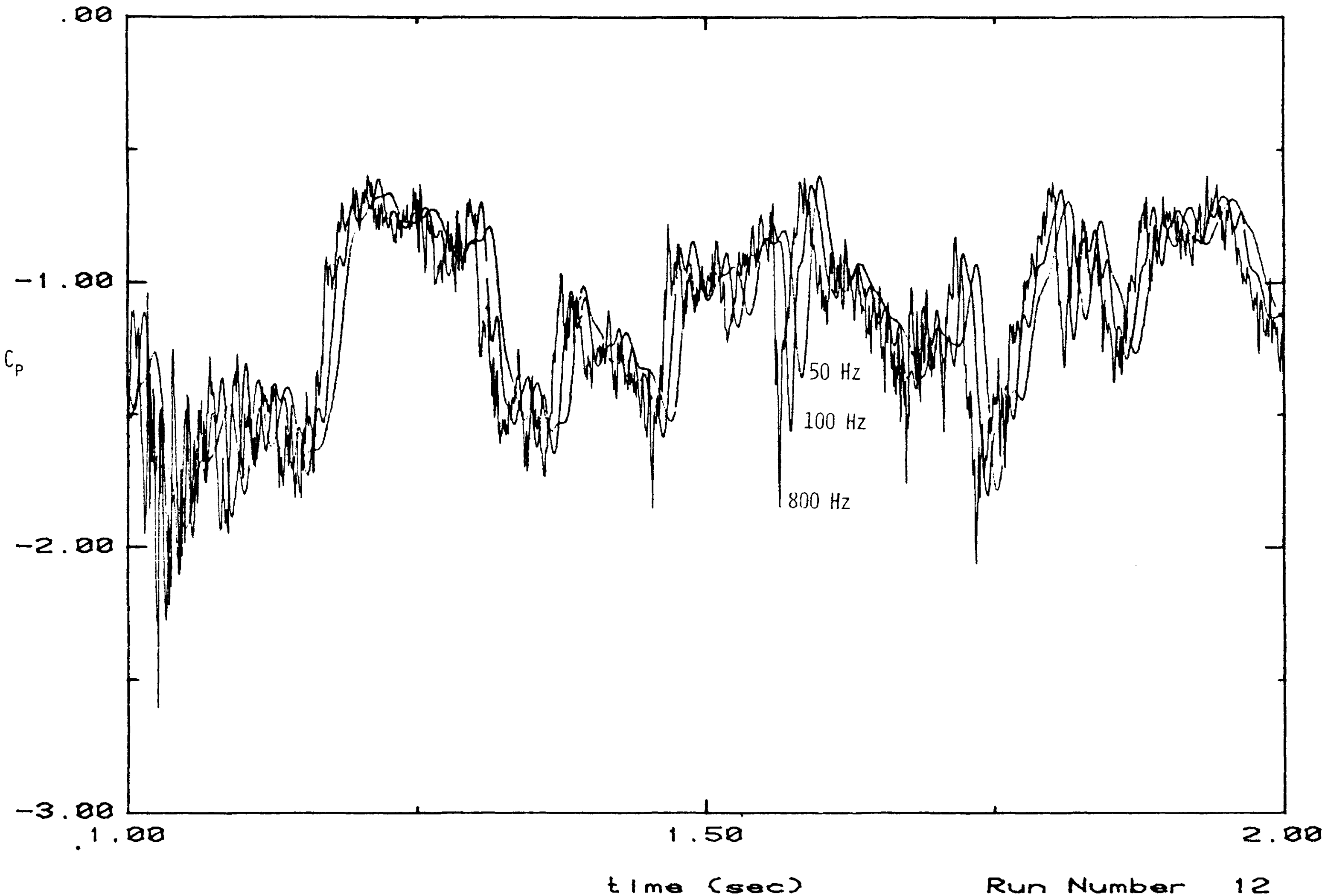


Figure 9. Time Trace of One Data Run with Three Filters

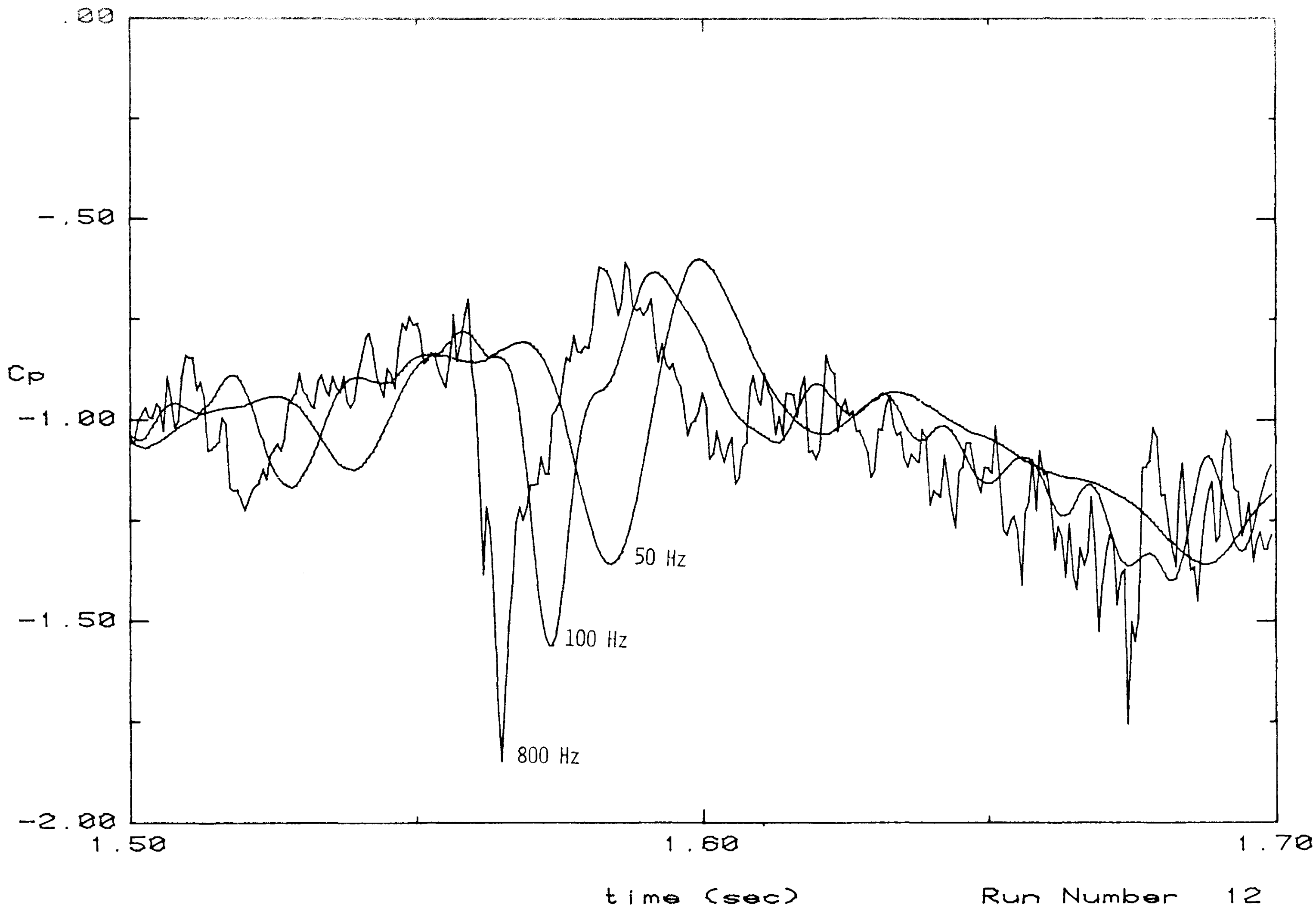


Figure 10. Expanded Time Trace of One Data Run with Three Filters

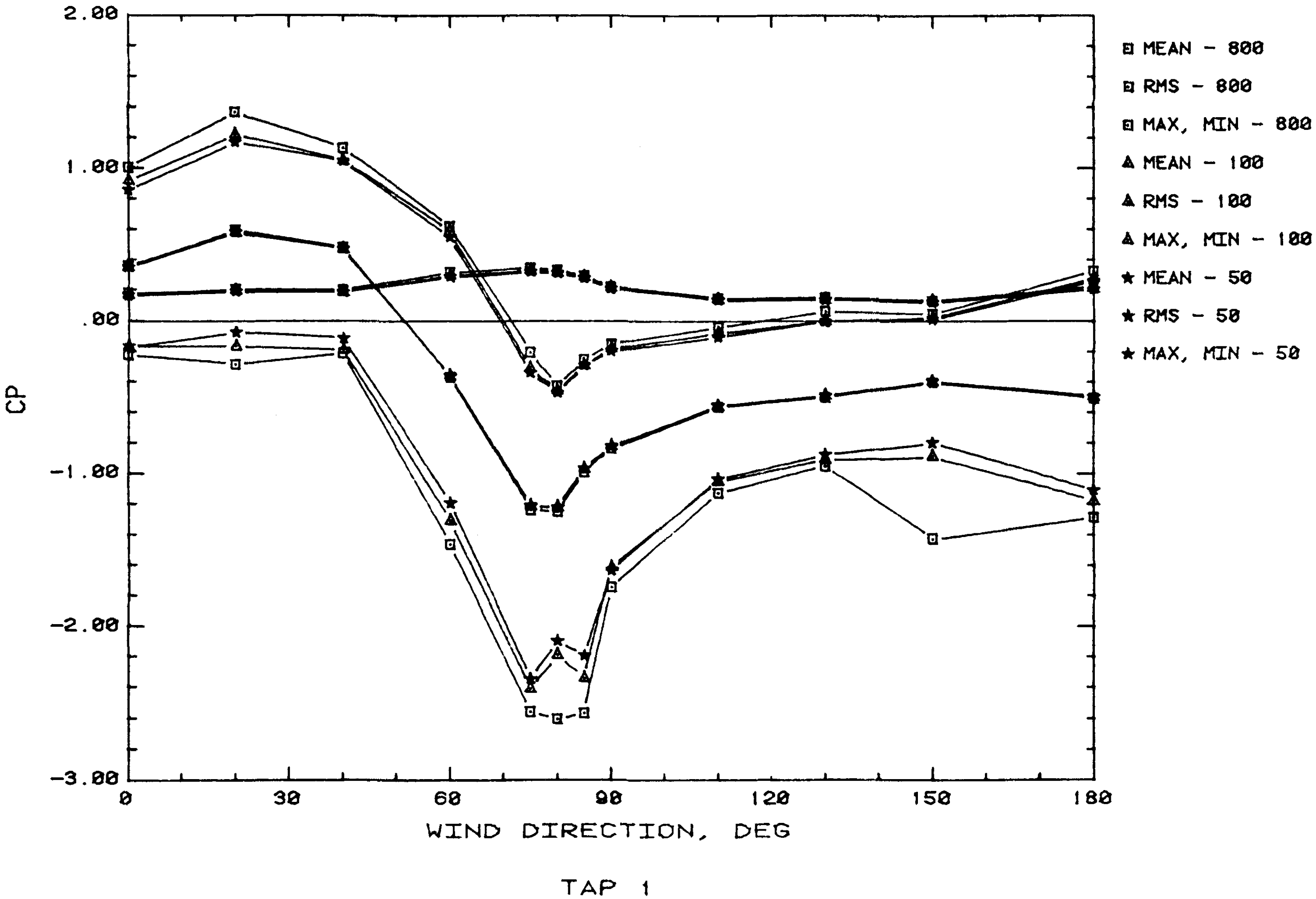
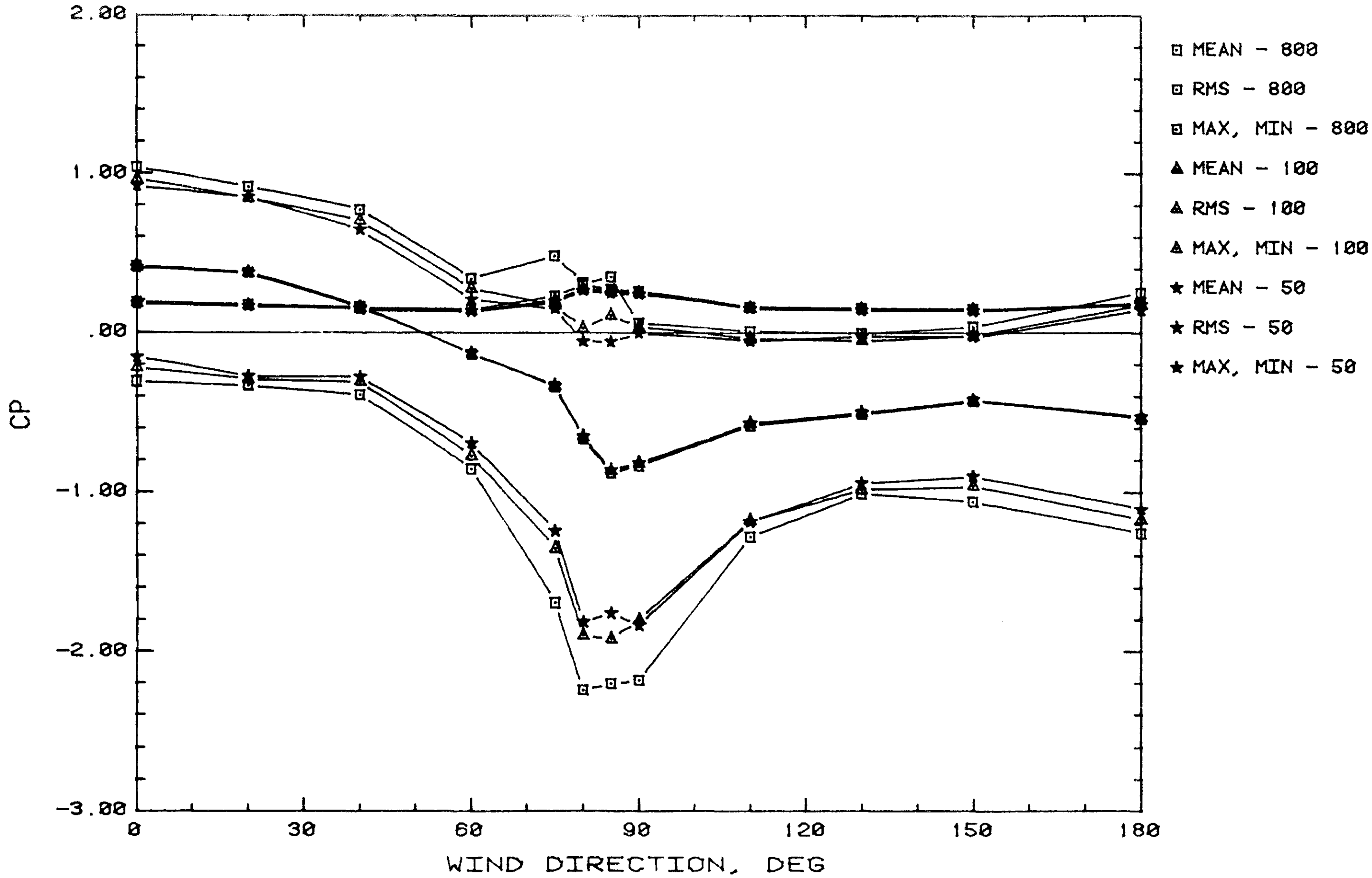


Figure 11. Variation of C_p mean, rms, maximum and minimum with Wind Direction for Each Tap



TAP 2

Figure 11 (con't). Variation of C_p mean, rms, maximum and minimum with Wind Direction for Each Tap

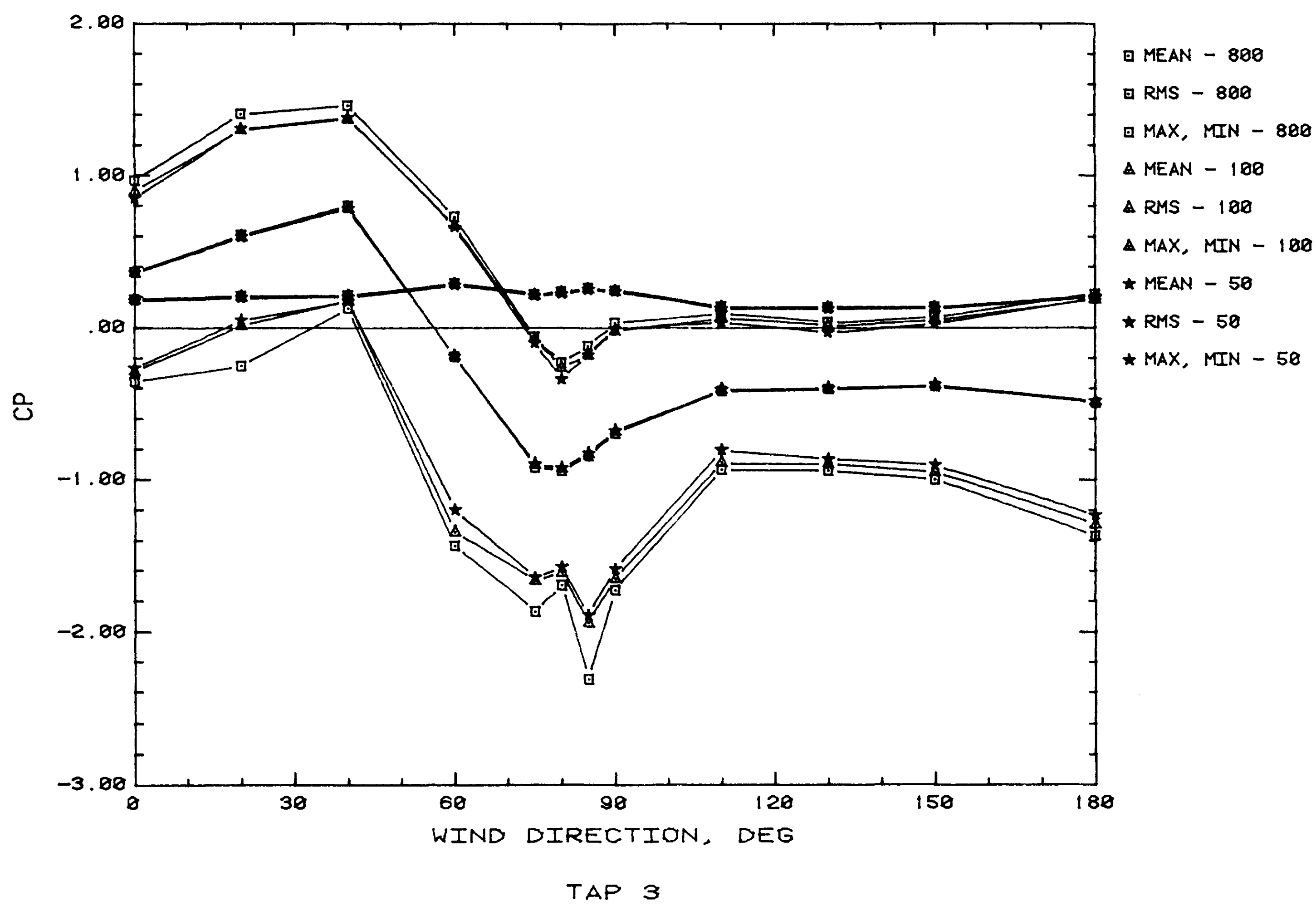
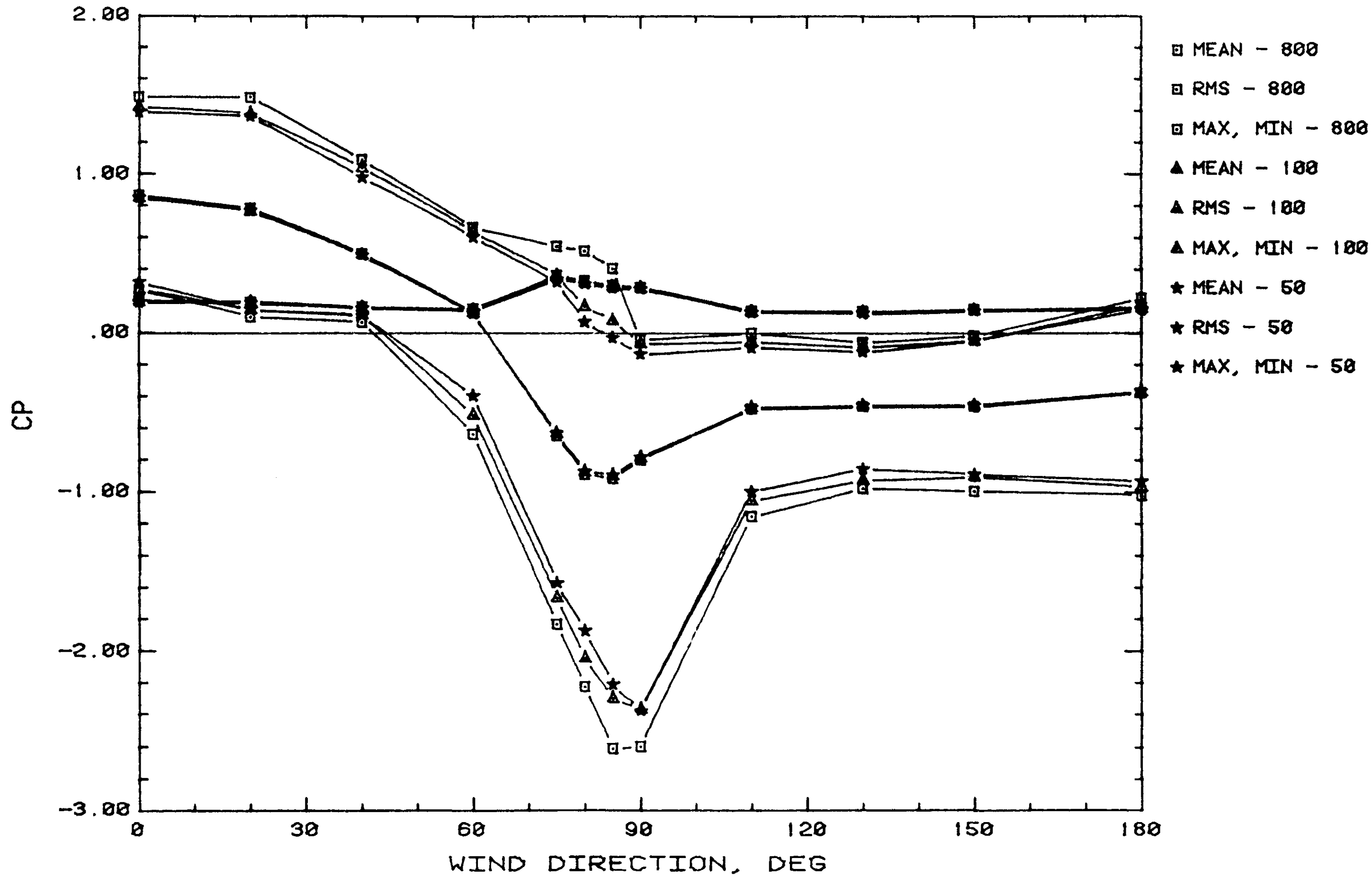


Figure 11 (con't). Variation of C_p mean, rms, maximum and minimum with Wind Direction for Each Tap



TAP 4

Figure 11 (con't). Variation of C_p mean, rms, maximum and minimum with Wind Direction for Each Tap

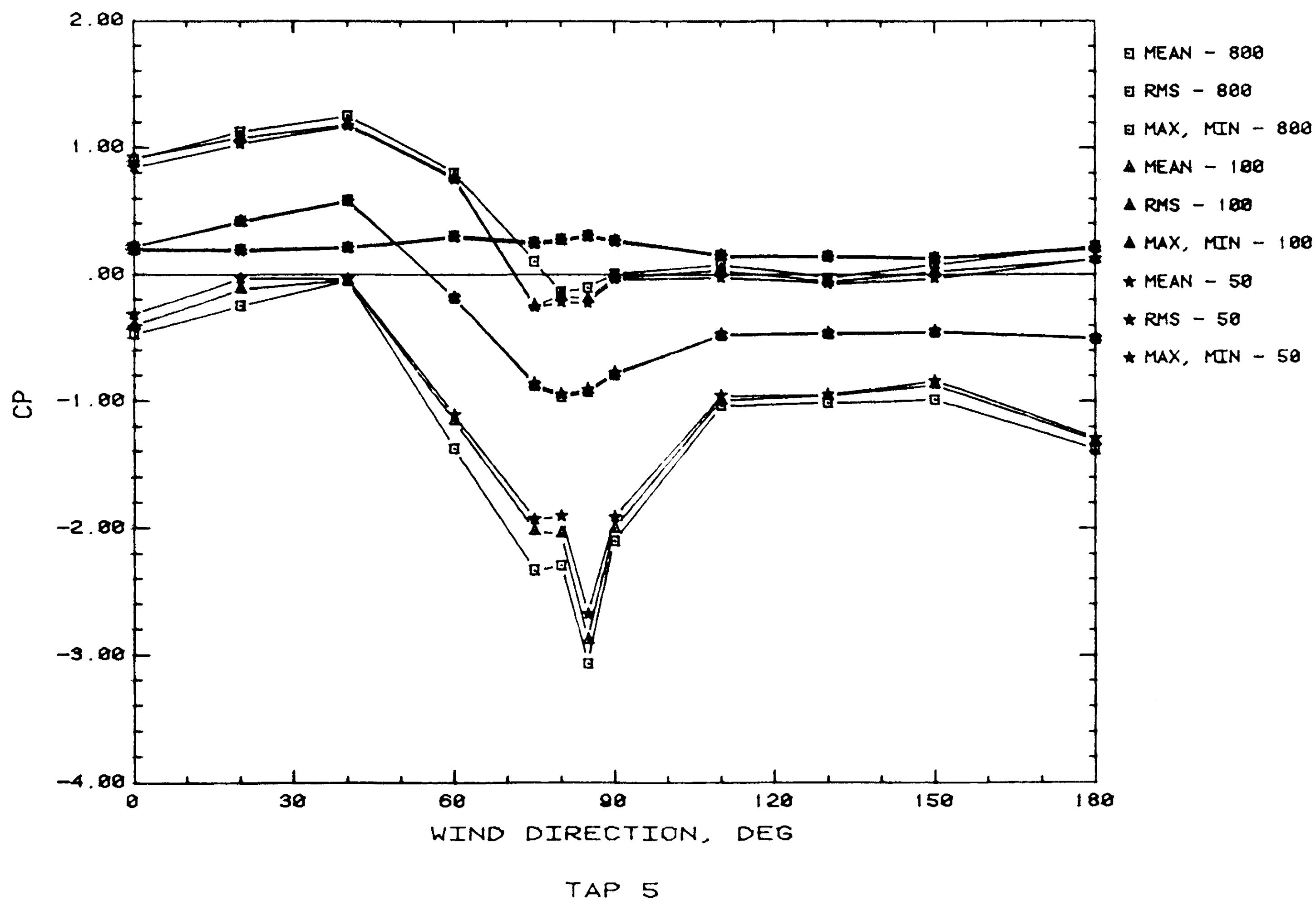
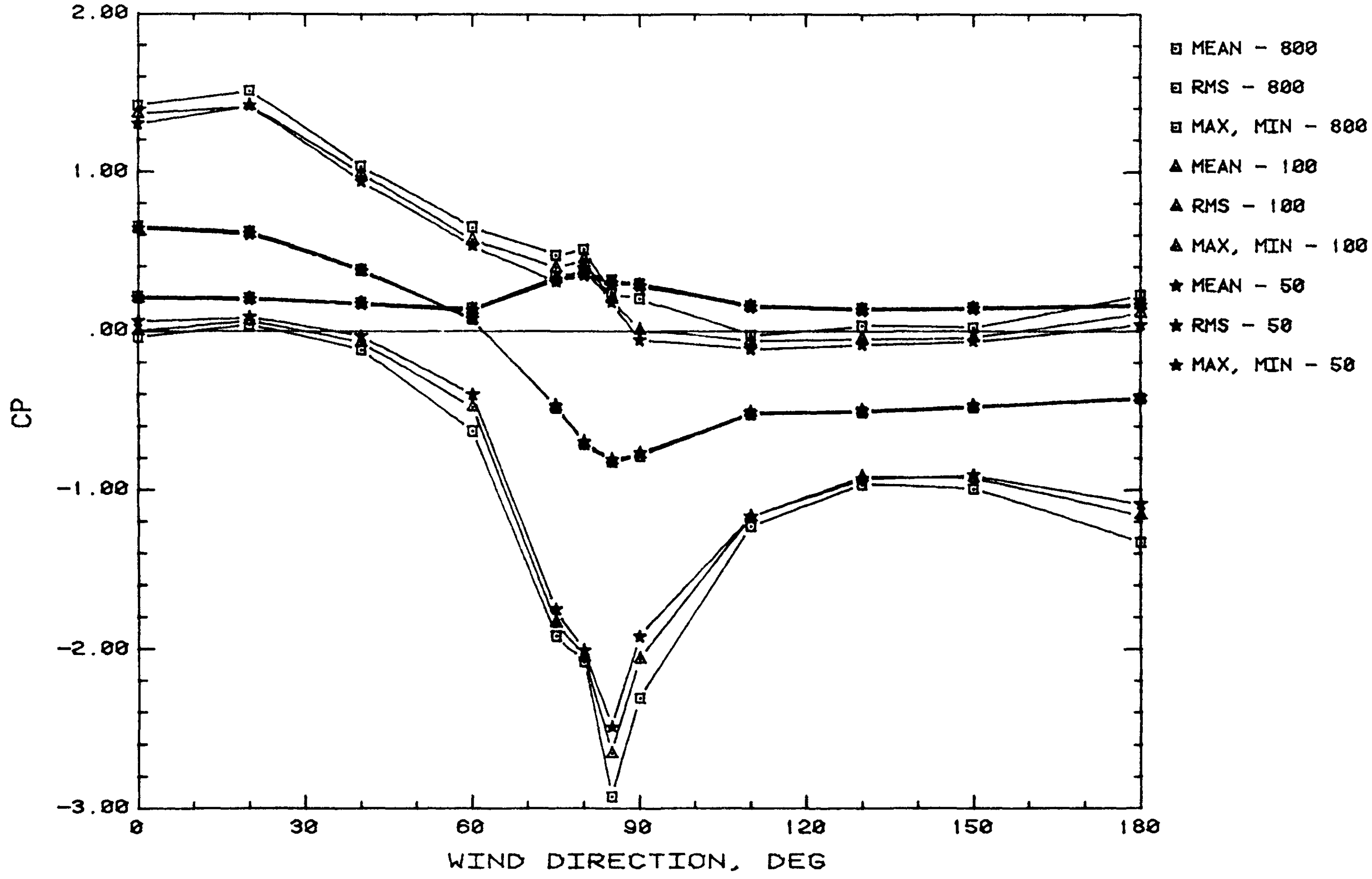


Figure 11 (con't). Variation of C_p mean, rms, maximum and minimum with Wind Direction for Each Tap



TAP 6

Figure 11 (con't). Variation of C_p mean, rms, maximum and minimum with Wind Direction for Each Tap

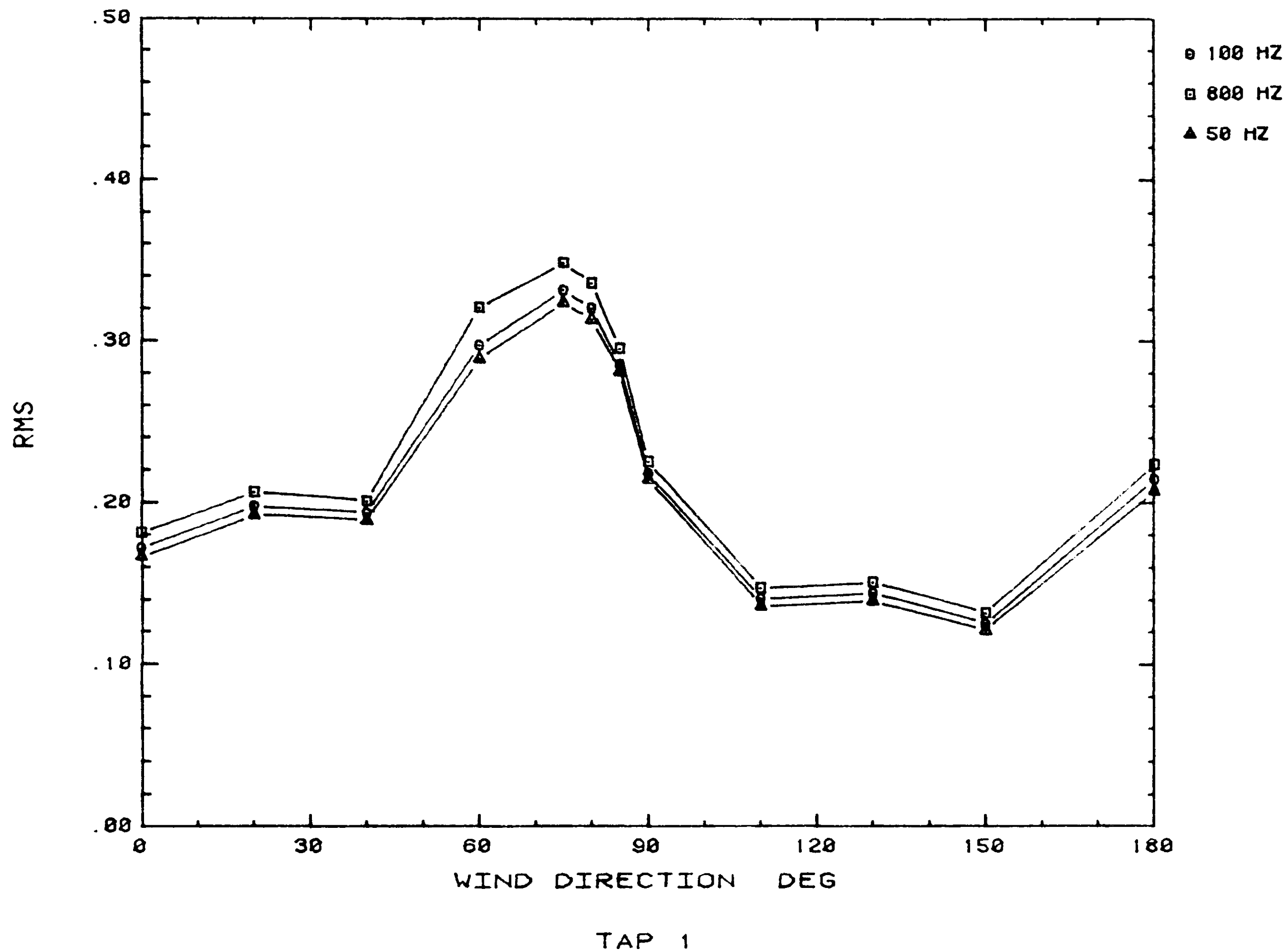
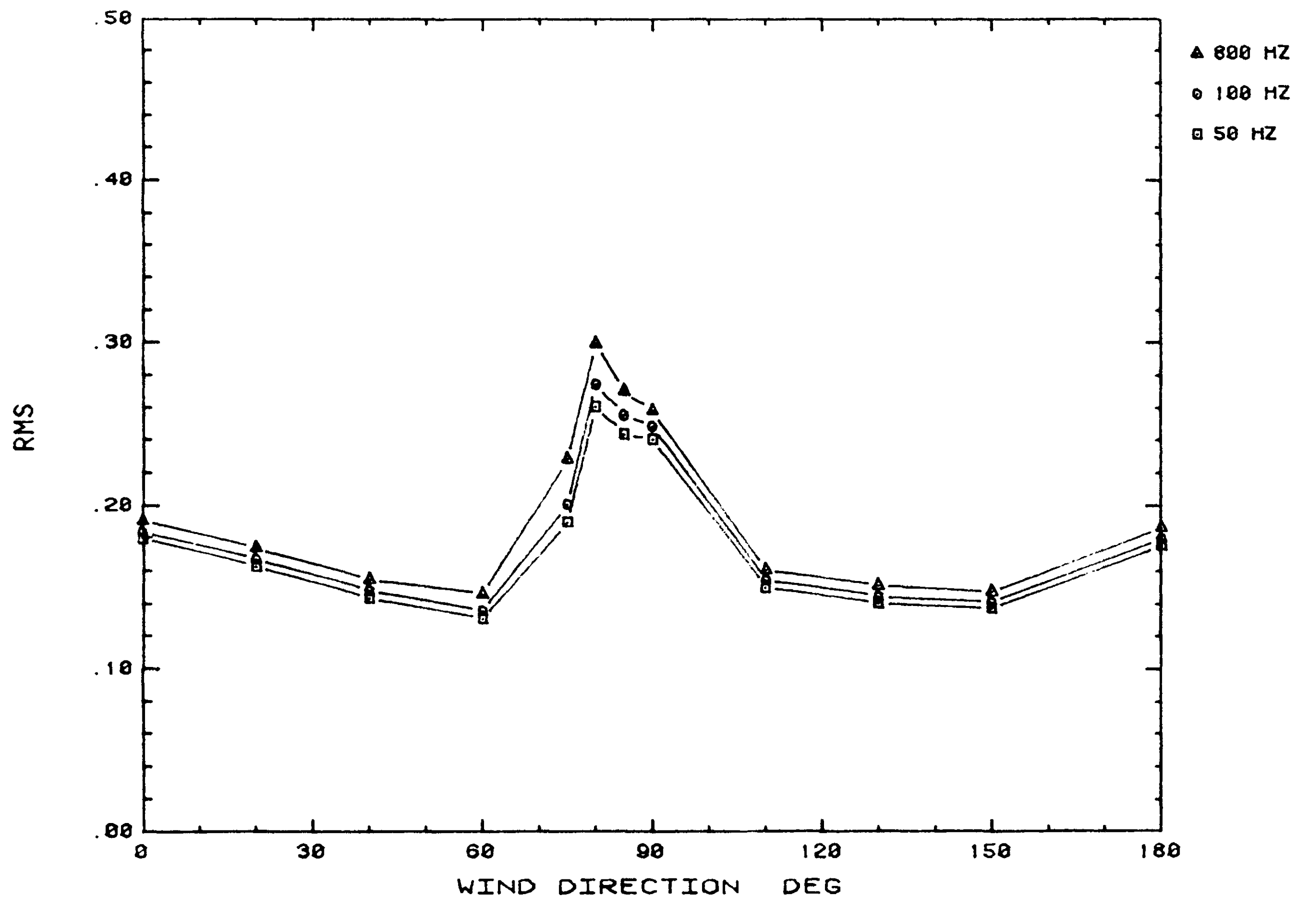


Figure 12. Variation of C_p rms with Wind Direction for Each Tap



TAP 2

Figure 12 (con't). Variation of C_p rms with Wind Direction for Each Tap

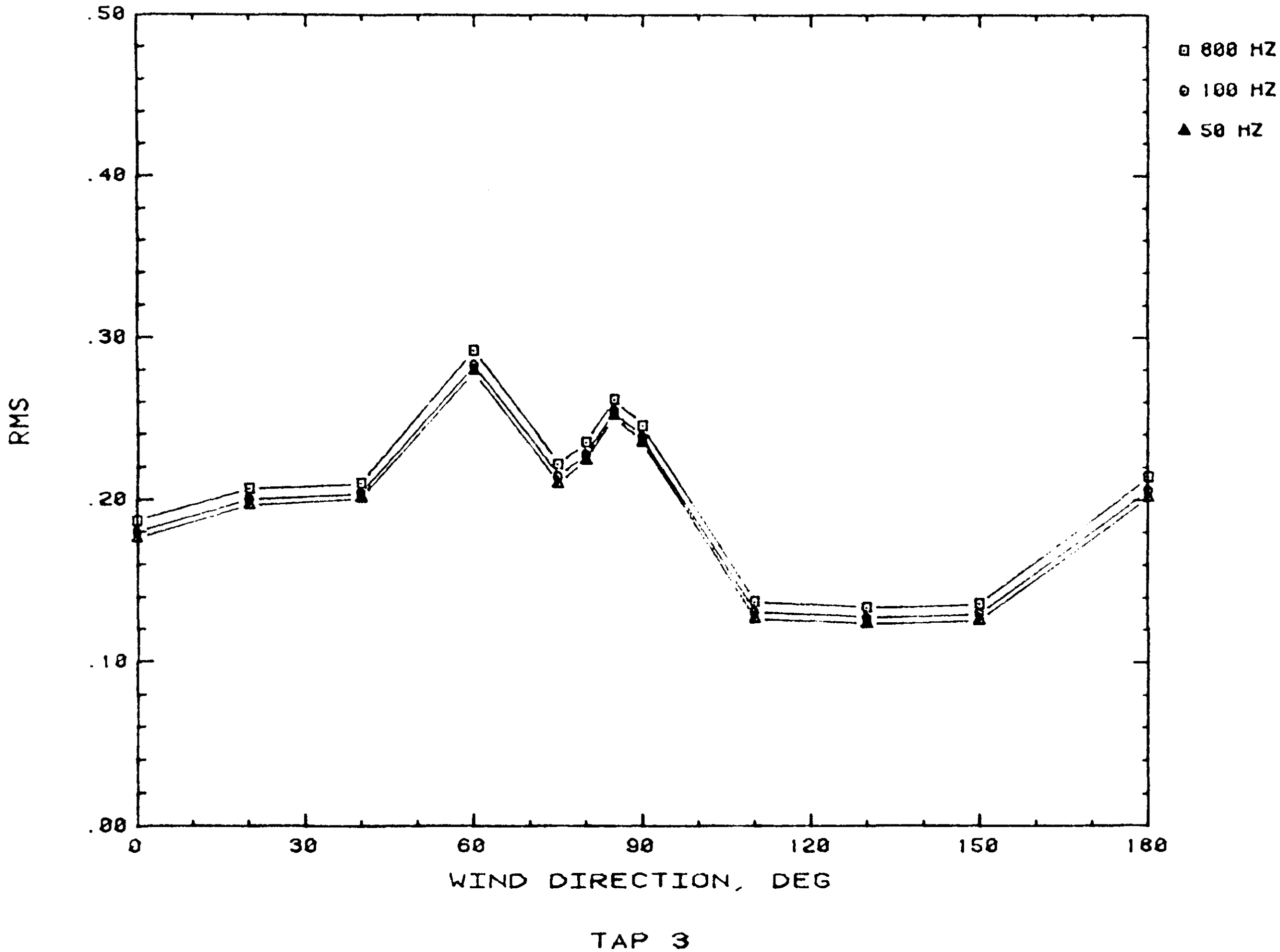


Figure 12 (con't). Variation of C_p rms with Wind Direction for Each Tap

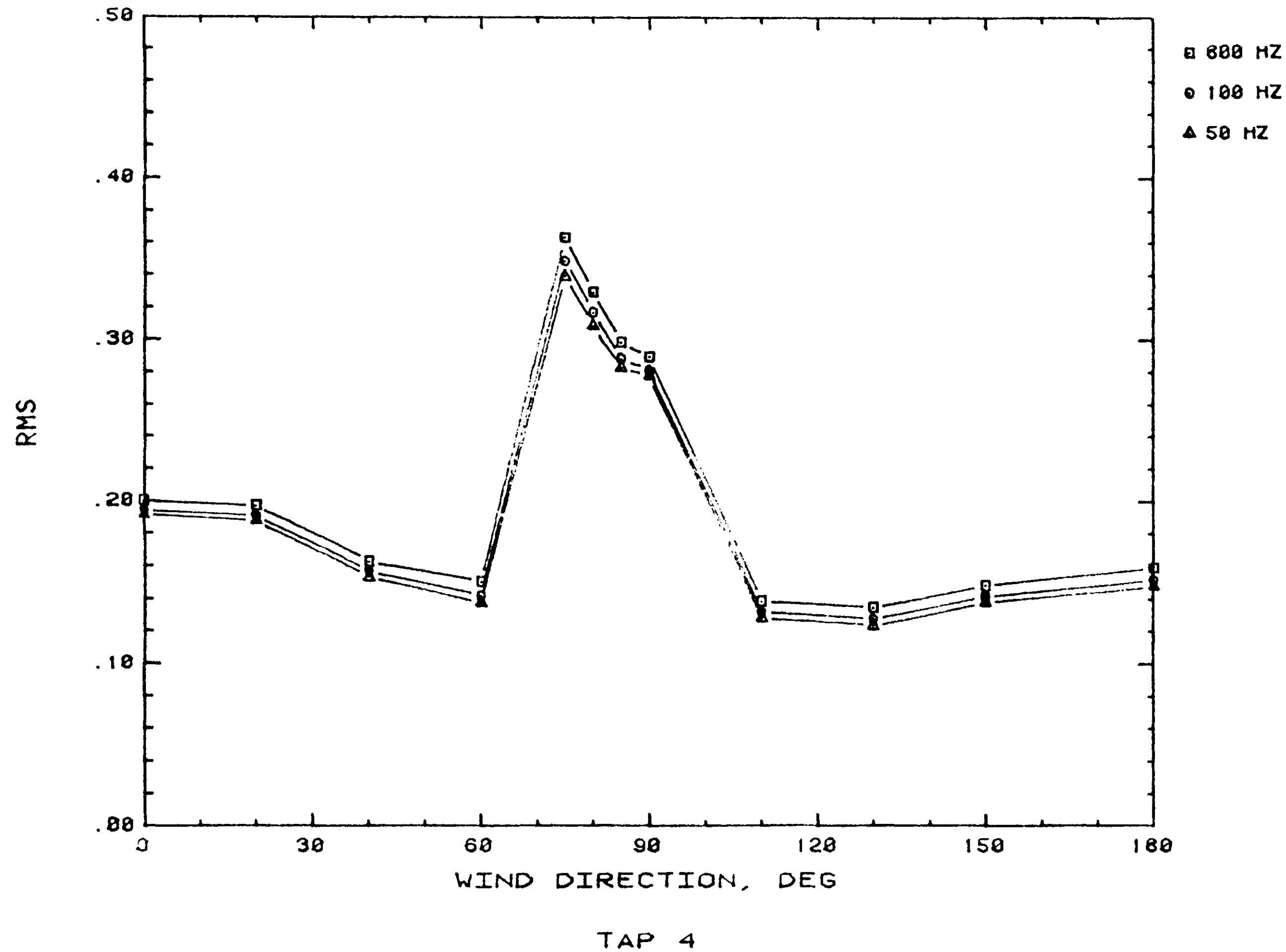
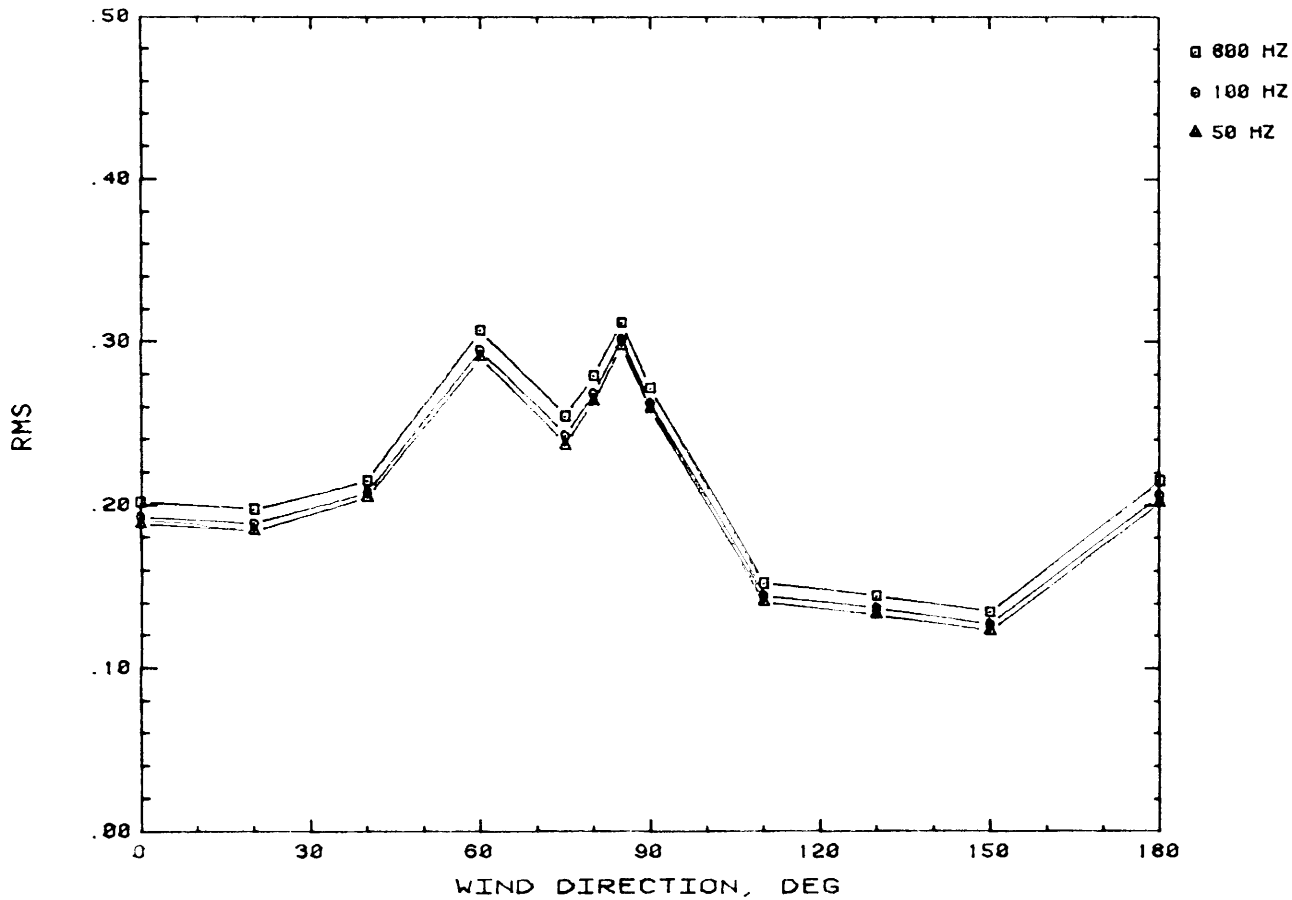


Figure 12 (con't). Variation of C_p rms with Wind Direction for Each Tap



TAP 5

Figure 12 (con't). Variation of C_p rms with Wind Direction for Each Tap

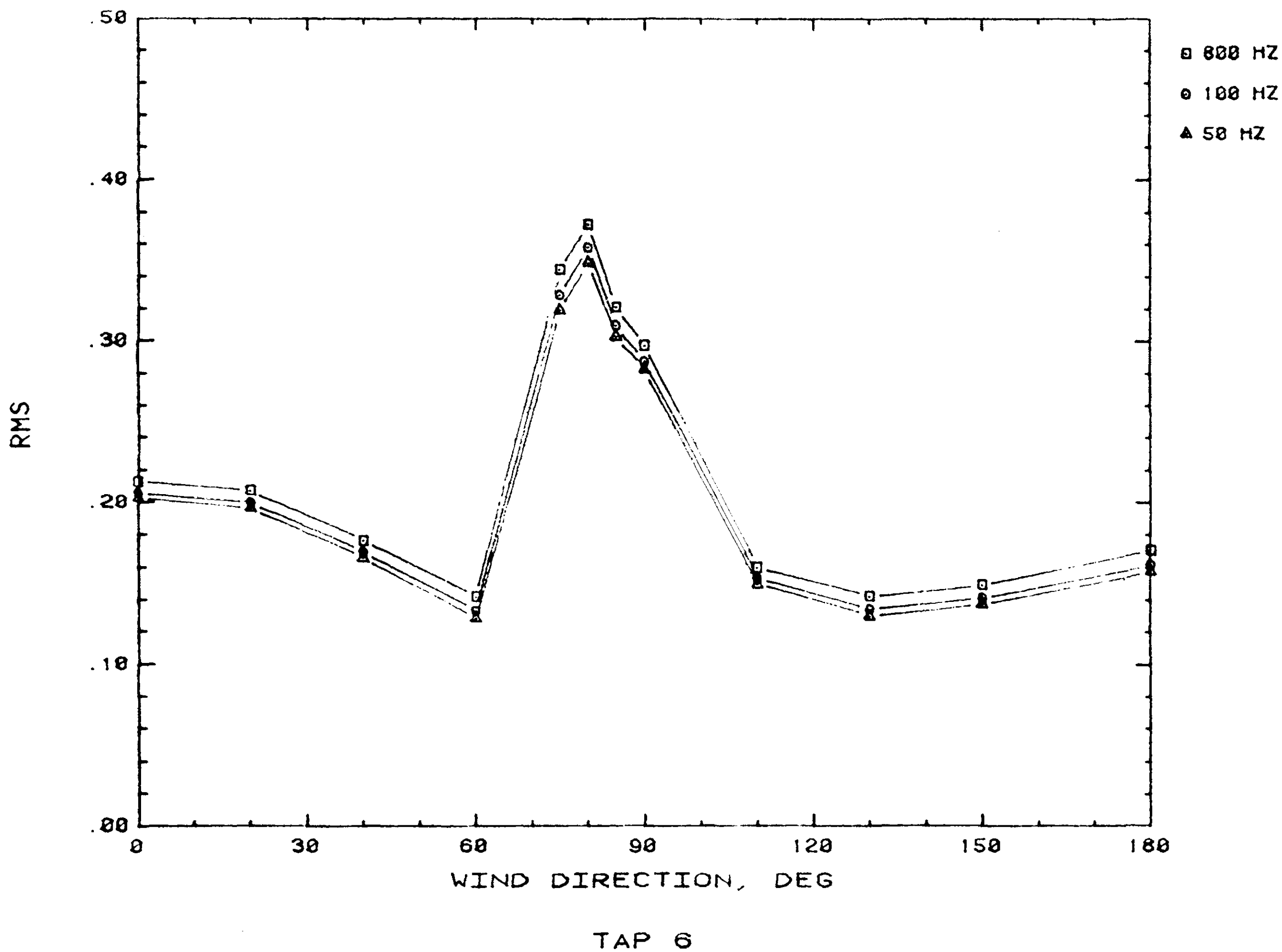


Figure 12 (con't). Variation of C_p rms with Wind Direction for Each Tap