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NOISE FIELD FOR SHADOWGRAPH MODEL ROCKET EXPERIMENTS

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TABLE OF CONTENTS

LIST OF FIGURES

1.0 INTRODUCTION

Measurements of the sound field, of the hot model rocket flow, are required as part of the study of Mach Wave radiation from supersonic rocket exhausts. Initially, a series of microphones will be positioned in the roof of the Shadowgraph tent, and the sound pressure levels recorded. At a later date, the microphones will be placed near the jet flow, and an attempt to correlate individual Mach Waves with their Shadowgraphs will be made. Also the propogation of the Mach Waves will be studied. The following calculations were made in order to estimate the overall levels and spectra at each of the various microphone positions. The overall sound power generated by the model rocket exhaust is first determined, and then the sound radiated to each point is found. The calculations are only approximate, especially for the nearest microphone position, but will allow the order of the sound levels to be obtained.

2.0 MODEL FLOW EXIT CONDITIONS, (GIVEN)

Exit diameter 1.0 in. = 0.08333 ft.
Exit Mach No. 2.7
Exit gas, total temperature - two values considered initially 400° F and 600° F.
Exit gas pressure = 14.7 psi (perfectly expanded).

3.0 CALCULATION OF OTHER EXIT CONDITIONS

Total temperature = 860° R or 1060° R.
Total pressure = stagnation pressure = pressure in chamber.
If $M = 2.7$, $p/p_o = 0.043$.

$$p_o = 14.7/0.043 = \underline{342 \text{ psi}}$$

$$\frac{p}{\rho T} = R \text{ when } p = 14.7 \text{ psi} = 14.7 \times 144 \text{ psf}$$

$$\rho = 0.00238 \text{ slugs/ft.}^3$$
$$T = 518^\circ \text{ R}$$

$$R = \frac{14.7 \times 144}{0.00238 \times 518} = \underline{1720}$$

ρ_o is the total or static density of the air.

$$T_o = 400^\circ \text{ F} = \underline{860^\circ \text{ R}} \qquad\qquad T_o = 600^\circ \text{ F} = \underline{1060^\circ \text{ R}}$$

$$\rho_o = \frac{342 \times 144}{860 \times 1720} = 0.0333 \qquad\qquad \rho_o = \frac{342 \times 144}{1060 \times 1720} = 0.0270 \text{ slugs/ft.}^3$$

Adiabatic Expansion

Saint - Venant and Wentzel Equation

$$V^2 = \frac{2\gamma}{\gamma - 1} \frac{P_o}{\rho_o} \left[1 - \left(\frac{P}{P_o}\right)^{(\gamma-1)/\gamma}\right]$$

γ = 1.4 to air

Exit Velocity

V_e = 2480 fps $\qquad\qquad$ V_e = 2760 fps

If convection speed of eddies = $0.5 V_e$

V_c = 1240 fps $\qquad\qquad$ V_c = 1380 fps

which is supersonic, relative to the ambient air in both cases.

Use V_e = 2480 fps.

Higher levels will be recorded for hotter flow.

Exit Density ρ_e

$$\frac{\rho}{\rho_o} = \left[\frac{2}{(\gamma - 1) M^2 + 2}\right]^{1/(\gamma - 1)}$$

ρ_e = 0.00353 Slugs/ft.^{3}

Exit Temperature T_e

T_e = 14.7 x 144/1720 x 0.00353 = 349° R

Exit Mass Flow = $\pi d^2/4 \times \rho_e \times V_e$

$= \pi \times 0.08333^2 \times 0.00353 \times 2480/4$

W_e = 0.0477 slugs/sec.

$$\text{Mechanical Power} = 0.676\, W_e V_e^2$$
$$= 0.676 \times 0.0477 \times 2480^2$$
$$= 1.97 \times 10^5 \text{ Watts}$$

4.0 ACOUSTIC POWER OF MODEL ROCKET

Say acoustic efficiency $= 0.25\ \%$

Then the acoustic power $= 0.25 \times 10^{-2} \times 1.97 \times 10^5 = 4.92 \times 10^2$ Watts

Overall Sound Power Generated OAPWL = 156.9 dB, re: 10^{-13} Watts.

5.0 SPECTRUM OF OVERALL SOUND GENERATED

Calculate spectrum from Figure 3 of Reference 1.

$D_e = 0.08333$ ft. $\quad D_e/V_e = 0.0000336$

$V_e = 2480$ fps $\quad V_e/D_e = 29200 \quad 10 \log_{10} (29200)\ 43.9$

f	fD_e/V_e	$10 \log_{10}\left(\frac{PWL_f}{OAWL} \times \frac{V_e}{D_e}\right)$	$\frac{PWL_f}{OAWL}$	PWL_f	octave Δf	PWL_{octave}
106	.00356	3	-40.9	116.0	18.7	134.7
212	.00712	10	-33.9	123.0	21.7	144.7
425	.0142	12	-31.9	125.0	24.7	149.7
850	.0285	11	-32.9	124.0	27.7	151.7
1700	.057	7.5	-36.4	120.5	30.7	151.2
3400	.114	2	-41.9	115.0	33.7	148.7
6800	.228	- 4	-47.9	109.0	36.7	145.7
13600	.457	- 9	-52.9	104.0	39.7	143.7

OAPWL = 157.3 dB*

*This is a little high by 0.7 dB.
Plot in Figure 1.

6.0 LEVEL AND SPECTRUM OF SOUND AT MICROPHONES

The rocket issues horizontally, the far field microphones will be hung in the roof of a canvas shed. Typical distances and positions are shown in Figure 2, and the dimensions are given in Table I.

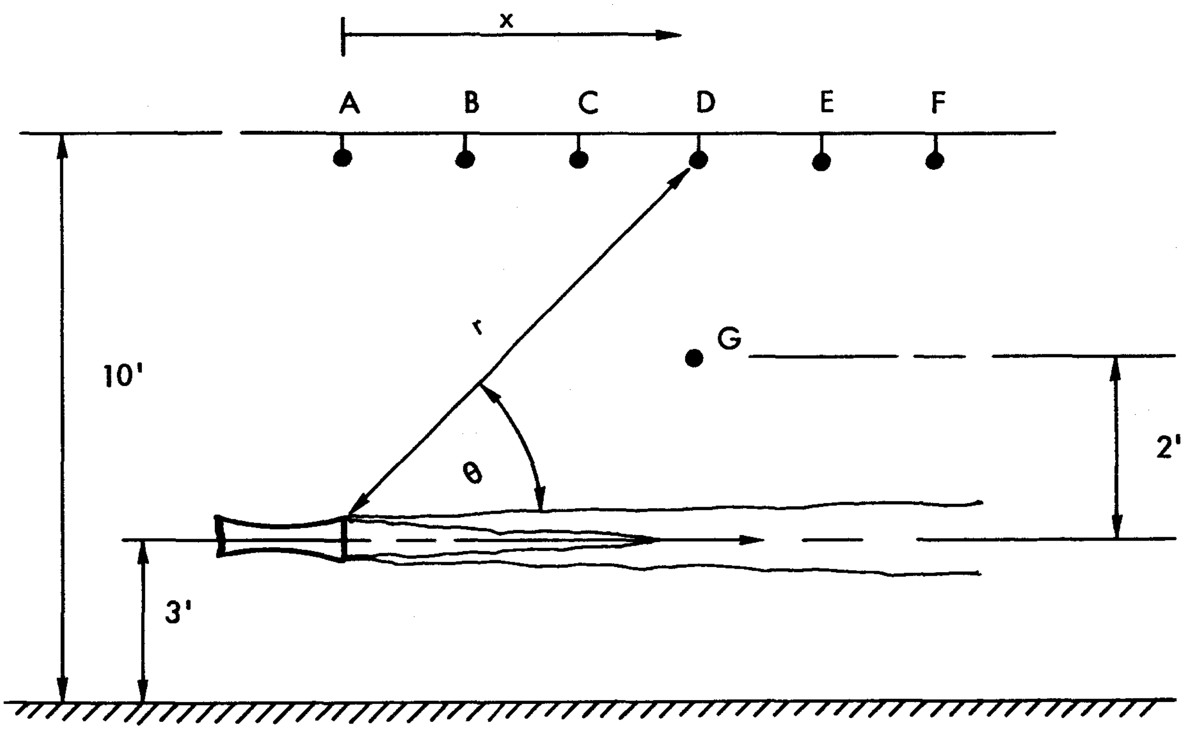

Figure 2: Position of Microphones

TABLE I DIMENSIONS OF MICROPHONE POSITIONS

Microphone	A	B	C	D	E	F	G
x feet	0	3	6	9	12	15	3
r feet	7.0	7.6	9.2	11.4	13.9	16.5	3.6
θ degrees	90	67	50	38	30	25	34

The directivity curves, needed for the calculation of the proportion of sound radiated to each microphone position, will fall between the results for a high speed rocket exhaust and a subsonic jet. The curves in Figure 3 will be used in the calculations, and they are based on the analyses of Reference 1. A possible criticism of these results is that they do not give high enough directivity values, as are suggested by the limited results of Reference 2.

The spectrum of Sound Pressure Level will be calculated at each microphone position on the basis of spherical radiation of the octave band power, and the addition of the appropriate directivity function value. An additional factor of 1 dB will be added to the results of C and D, and 2 dB to E and F, since the sound will be generated from points further downstream in the flow, than the nozzle exit from where r is measured. An additional factor of 3 dB will be added to the results for G, to allow for near field effects.

Microphone	A	B	C	D	E	F	G
r	7.0	7.6	9.2	11.4	13.9	16.5	3.6
$4 \pi r^2$	615	725	1040	1630	2420	3420	113
$10 \log_{10}(4 \pi r^2)$	27.9	29.6	30.2	32.1	33.8	35.3	20.5

The Sound Pressure Levels in Octave Bands are calculated for each point by a similar calculation to that given below in Table II for one particular microphone.

For each octave band, at each microphone point, the Octave Band Sound Pressure Level is given by

$$SPL_{\Delta f} = PWL_{\Delta f} - 10 \log_{10} (4 \pi r^2) + DI + C$$

where

$PWL_{\Delta f}$ is the Octave Band Acoustic Power generated by the rocket.

r is the distance to the microphone

DI is the Directivity Index

and C is the correction mentioned above.

TABLE II CALCULATION OF SPECTRUM FOR MICROPHONE POSITION D

f (cps)	$PWL_{\Delta f}$	- 32.1	DI + 1.0	$SPL_{\Delta f}$ (dB)
106	134.7	102.6	5.3	107.9
212	144.7	112.6	5.6	118.2
425	149.7	117.6	5.6	123.2
850	151.7	119.6	5.6	125.2
1700	151.2	119.1	5.5	124.6
3400	148.7	116.6	5.3	121.9
6800	145.7	113.6	5.0	118.6
13600	143.7	111.6	4.6	116.2
			Overall SPL =	130.7

TABLE III OCTAVE BAND SOUND PRESSURE LEVELS

Microphone	A	B	C	D	E	F	G
Octave Band Center Frequency							
106	103.3	106.2	108.4	107.9	106.8	105.5	121.8
212	113.9	116.8	118.8	118.2	116.8	115.3	132.0
425	119.4	122.3	124.1	123.2	121.7	120.1	136.9
850	124.9	124.8	126.3	125.2	123.5	121.7	138.8
1700	122.9	124.7	124.9	124.6	122.7	120.7	138.1
3400	119.9	122.6	123.5	121.9	119.8	117.9	135.3
6800	117.4	119.9	120.5	118.6	116.4	114.4	132.0
13600	116.0	118.2	118.5	116.2	113.7	111.4	129.3
Overall SPL	128.0	130.2	131.7	130.7	128.9	127.1	144.2

All results are dB, re: 0.0002 dyne/cm^2.

7.0 CONCLUDING REMARK

In view of these calculated levels, which may be slightly low, it is recommended that a microphone with a range of 120 to 150 dB, re: 0.0002 dyne/cm^2 be selected for the measurements. This will probably rule out a piezo-electric device and it is recommended that Bruel and Kjaer 0.25 in. condenser microphones be considered for this application. Not only have they a good range of response, including the calculated levels, but they are reasonably small and compact, which will help in the near field correlation studies.

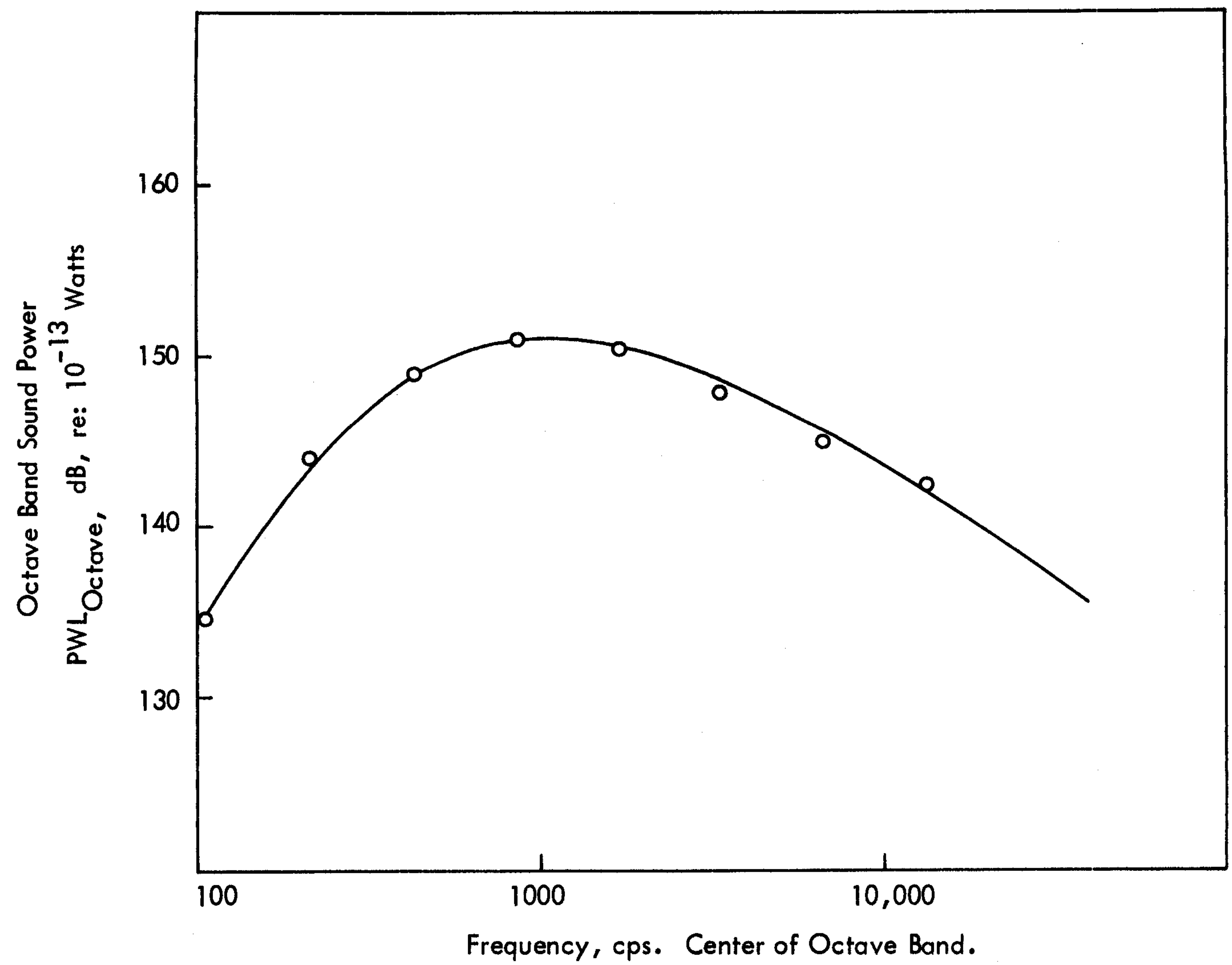

Figure 1: Octave Band Acoustic Power Generated by Air Model Rocket

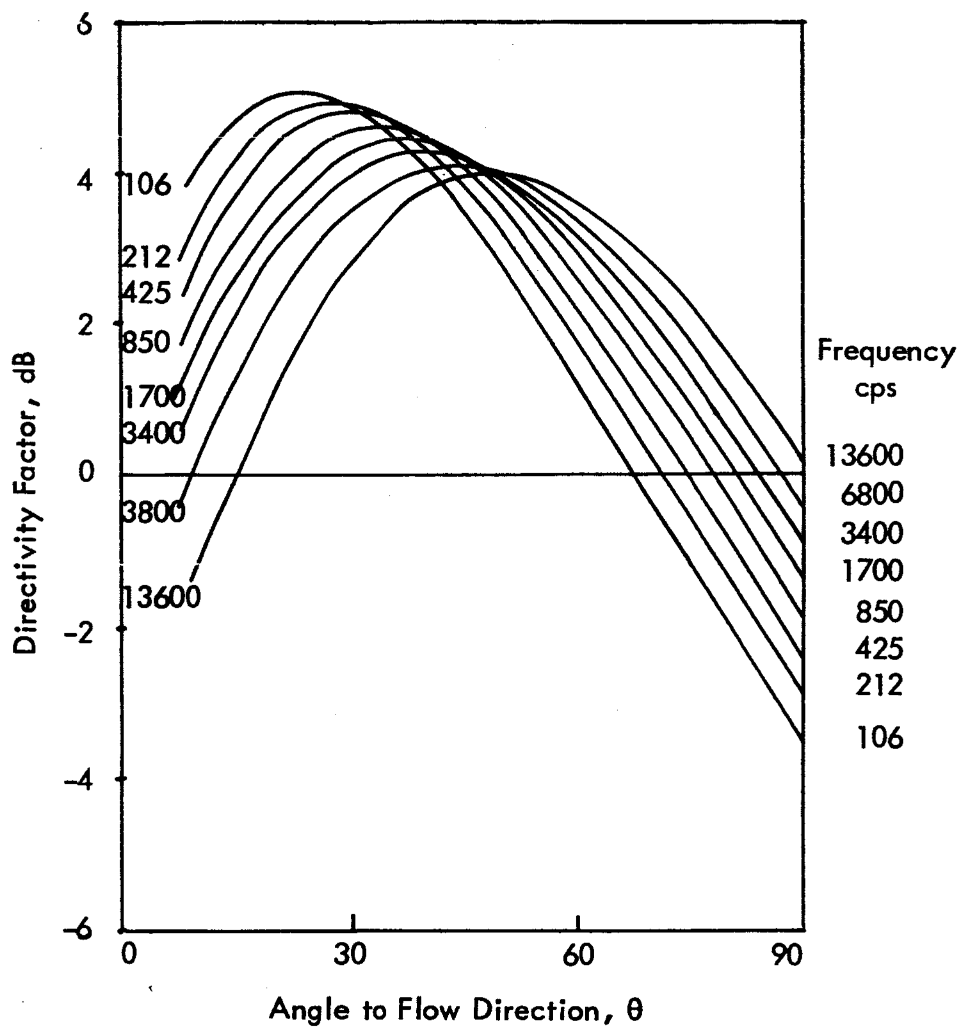

Figure 3: Directivity Curves Used in Prediction

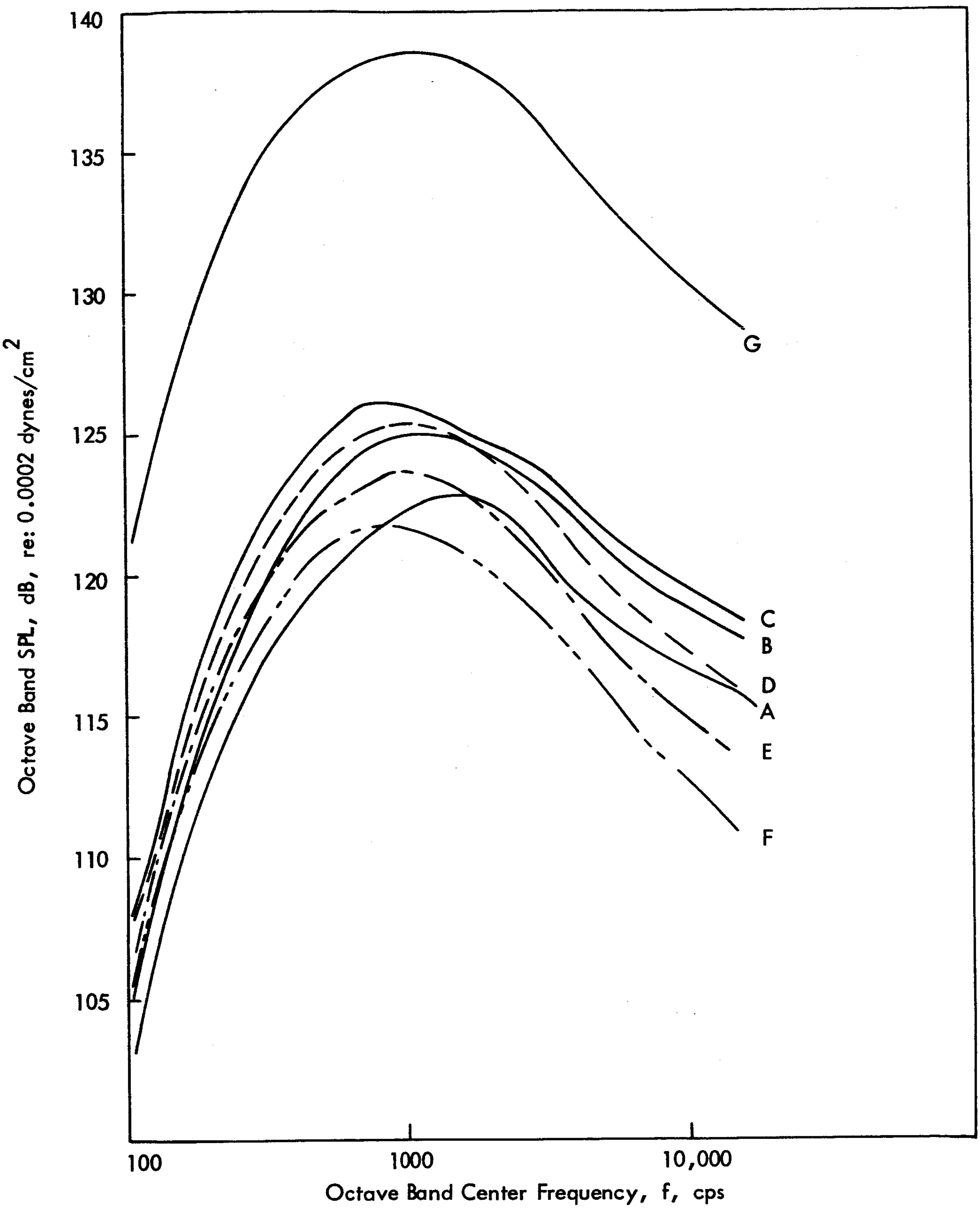

Figure 4: Octave Band Sound Pressure Levels