research report

WYLE LABORATORIES - RESEARCH STAFF

REPORT WR 72-2

TABLES OF ABSORPTION AND VELOCITY OF SOUND IN STILL AIR AT 68° F (20° C)

WYLE LABORATORIES
TESTING DIVISION HUNTSVILLE FACILITY

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WYLE LABORATORIES
RESEARCH DIVISION, HUNTSVILLE FACILITY

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ABSTRACT

Tables are presented for the absorption and velocity of sound in still air at 68° F (20° C). The absorption is presented in dB/1000 ft, dB/Km, and aB/sec. The velocity is presented in 1000 ft/sec. The tables cover the frequency range of 12 Hz - 1 MHz and for relative humidities of 0%-100%. An appendix is included which presents analytical expressions that will duplicate the tables within 3% over all frequencies and humidities.

INTRODUCTION

These tables and graphs are an interim step in the process of developing a comprehensive set of tables for absorption of sound in still air. They have been produced because of a need for such results which was expressed at the Helicopter Noise Symposium in Durham, North Carolina, September 1971. They should be viewed as an interim effort, and as being accurate only at the stated temperature. For those that need analytical expressions for the absorption and velocity such expressions are discussed in the Appendix.

The tables give the % relative humidity, temperature, one-third octave band center frequencies, absorption in dB/1000 ft, dB/Km, and dB/sec along with the velocity in 1000 ft/sec. They cover the frequency range of 12 Hz - 1 MHz and humidity range of 0% relative humidity to 100% relative humidity.

The tables have been produced from the theoretical technique which is described in Reference 1. The only modification which has been made is that the calculation technique for rotational relaxation has been replaced with a single rotational rate constant for air which has been taken from Reference 2. This modification affects the results only at the higher frequencies and brings the calculations into excellent agreement with experimental data at these frequencies. The agreement between the calculations and available experimental data in the audible frequency range can be viewed in Reference 1. At frequencies below 100 Hz no comparison has been made with experimental data because of the lack of such data.

For extremely dry air (less than 10% relative humidity) there is some difficulty in assessing the accuracy of the calculations below 100 Hz. However, the calculated values in this range reflect the best agreement with available data at higher frequencies.

The accuracy of the tables is different for different frequencies. For the range of 12 Hz - 100 Hz the calculated values may be in error as much as 50% with the error decreasing with increasing frequency. Over the rest of the frequency range the error in the calculations is less than 5% which is as good or better than experimental accuracy. The tables have been calculated for more digits than for which significance can be ascribed. This has been done for computational convenience. All of the absorption measurements should be regarded as significant to only one decimal place and the velocity (in 1000 ft/sec) is significant to four decimal places.

The velocity calculations include both relaxational and humidity effects and are in fair agreement with the experimental data in Reference 3.

REFERENCES

1. Evans, L.B. Bass, H.E., and Sutherland, L.C., J. Acoust. Soc. Amer., 51, 0000 (1972) (Probably March or May issue).

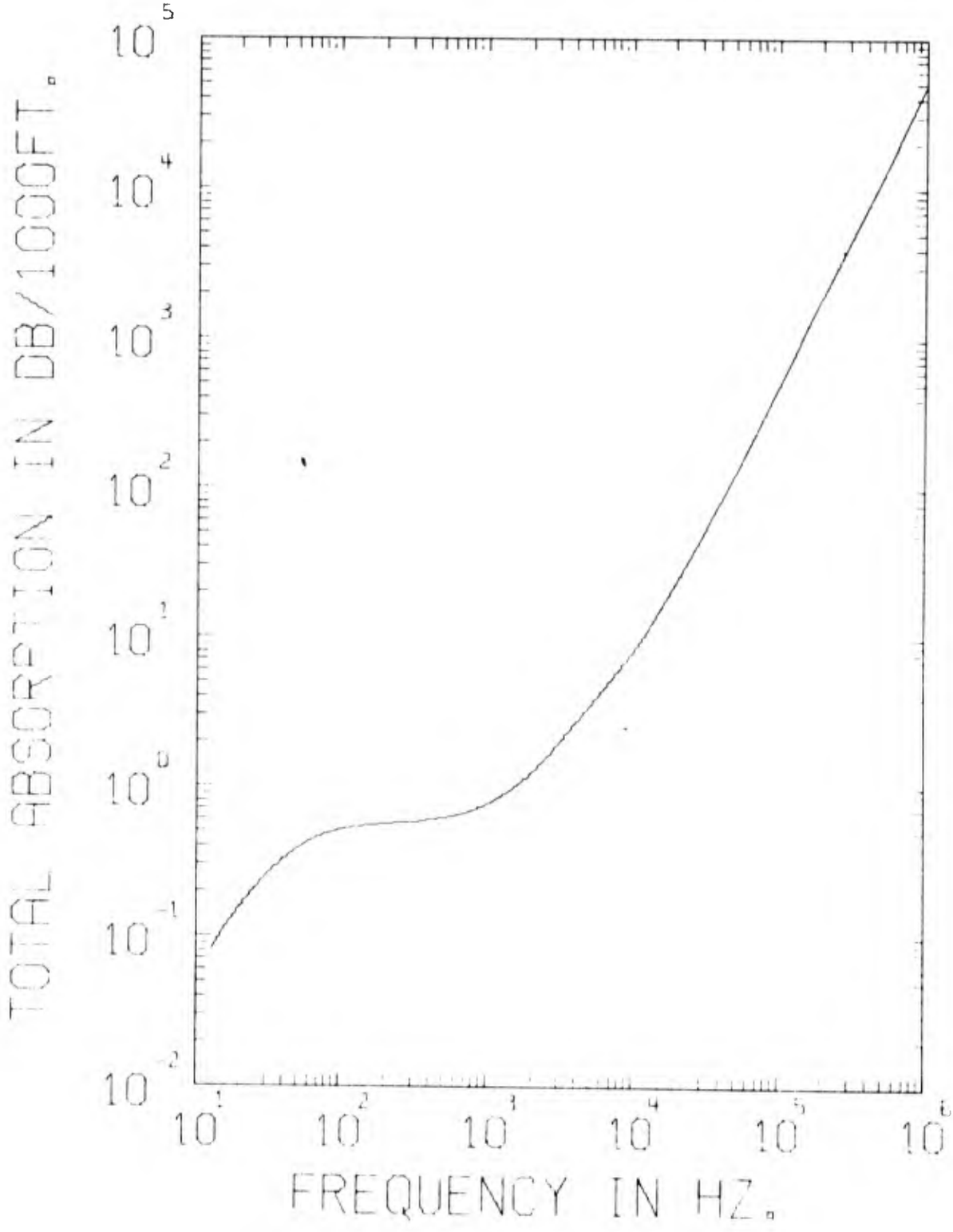
2. Greenspan, M., J. Acoust. Soc. Amer., 31, 155-160 (1959).

3. Harris, C.M., J. Acoust. Soc. Amer., 49, 890-893 (1971).

LIST OF GRAPHS AND TABLES

GRAPHS AND TABLES

SOUND ABSORPTION IN STILL AIR FOR 0% RELATIVE HUMIDITY.

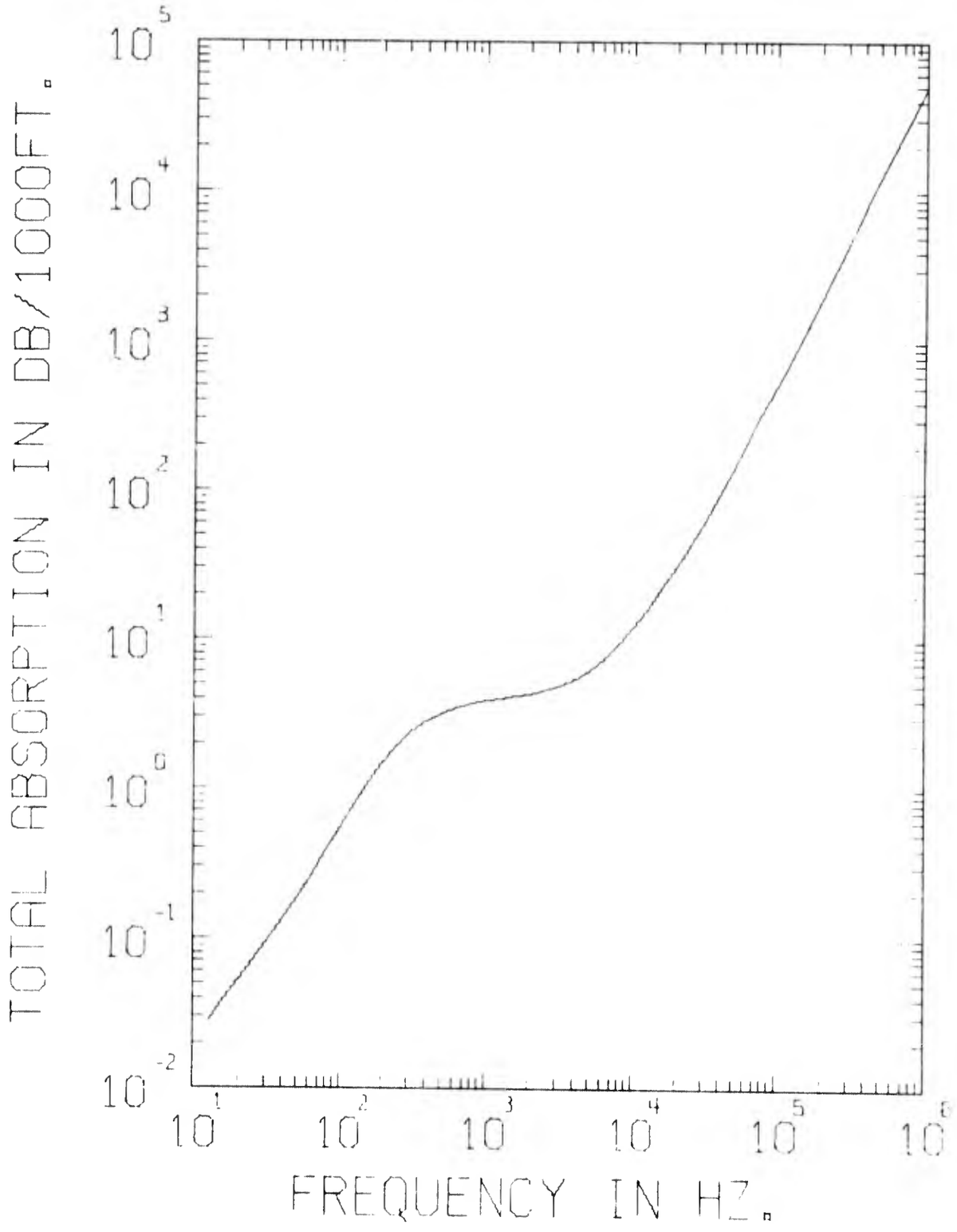


ABSORPTION AND VELOCITY OF SOUND IN STILL AIR

RELATIVE HUMIDITY = 0.0% TEMPERATURE = 68. DEGREES F

FREQUENCY (HZ)	ABSORPTION (DB/1000FT)	ABSORPTION (DB/KM)	ABSORPTION (DB/SEC)	VELOCITY (1000FT/SEC)
12.	0.074	0.24	0.083	1.126826
16.	0.114	0.37	0.128	1.126861
20.	0.154	0.51	0.174	1.126892
25.	0.204	0.67	0.230	1.126928
31.	0.258	0.85	0.291	1.126967
40.	0.327	1.07	0.368	1.127013
50.	0.384	1.26	0.433	1.127050
63.	0.436	1.43	0.491	1.127085
80.	0.479	1.57	0.539	1.127112
100.	0.509	1.67	0.573	1.127131
125.	0.531	1.74	0.598	1.127145
160.	0.548	1.80	0.618	1.127154
200.	0.560	1.84	0.631	1.127161
250.	0.571	1.87	0.643	1.127164
315.	0.582	1.91	0.656	1.127167
400.	0.596	1.96	0.672	1.127169
500.	0.615	2.02	0.694	1.127170
630.	0.645	2.11	0.727	1.127171
800.	0.692	2.27	0.780	1.127172
1000.	0.759	2.49	0.855	1.127172
1250.	0.861	2.82	0.970	1.127172
1600.	1.032	3.38	1.163	1.127172
2000.	1.262	4.14	1.423	1.127173
2500.	1.588	5.21	1.790	1.127174
3150.	2.052	6.73	2.313	1.127177
4000.	2.696	8.84	3.039	1.127178
5000.	3.481	11.42	3.923	1.127180
6300.	4.541	14.89	5.118	1.127182
8000.	6.032	19.79	6.799	1.127183
10000.	8.013	26.28	9.032	1.127184
12500.	10.918	35.81	12.306	1.127186
16000.	15.901	52.15	17.923	1.127187
20000.	22.978	75.37	25.901	1.127187
25000.	33.967	111.41	38.288	1.127187
31500.	51.849	170.06	58.443	1.127188
40000.	81.405	267.01	91.759	1.127188
50000.	125.152	410.50	141.070	1.127188
63000.	196.544	644.66	221.542	1.127188
80000.	314.677	1032.14	354.700	1.127188
100000.	489.613	1605.93	551.885	1.127188
125000.	762.945	2502.46	859.982	1.127188
160000.	1247.652	4092.30	1406.338	1.127188
200000.	1947.377	6387.39	2195.059	1.127188
250000.	3040.696	9973.48	3427.435	1.127188
315000.	4825.242	15826.79	5438.953	1.127188
400000.	7778.418	25513.21	8767.734	1.127188
500000.	12151.711	39857.61	13697.258	1.127188
630000.	19289.883	63270.81	21743.316	1.127188
800000.	31102.625	102016.56	35058.496	1.127188
1000000.	48595.793	159394.19	54776.578	1.127188

SOUND ABSORPTION IN STILL AIR FOR 1% RELATIVE HUMIDITY.

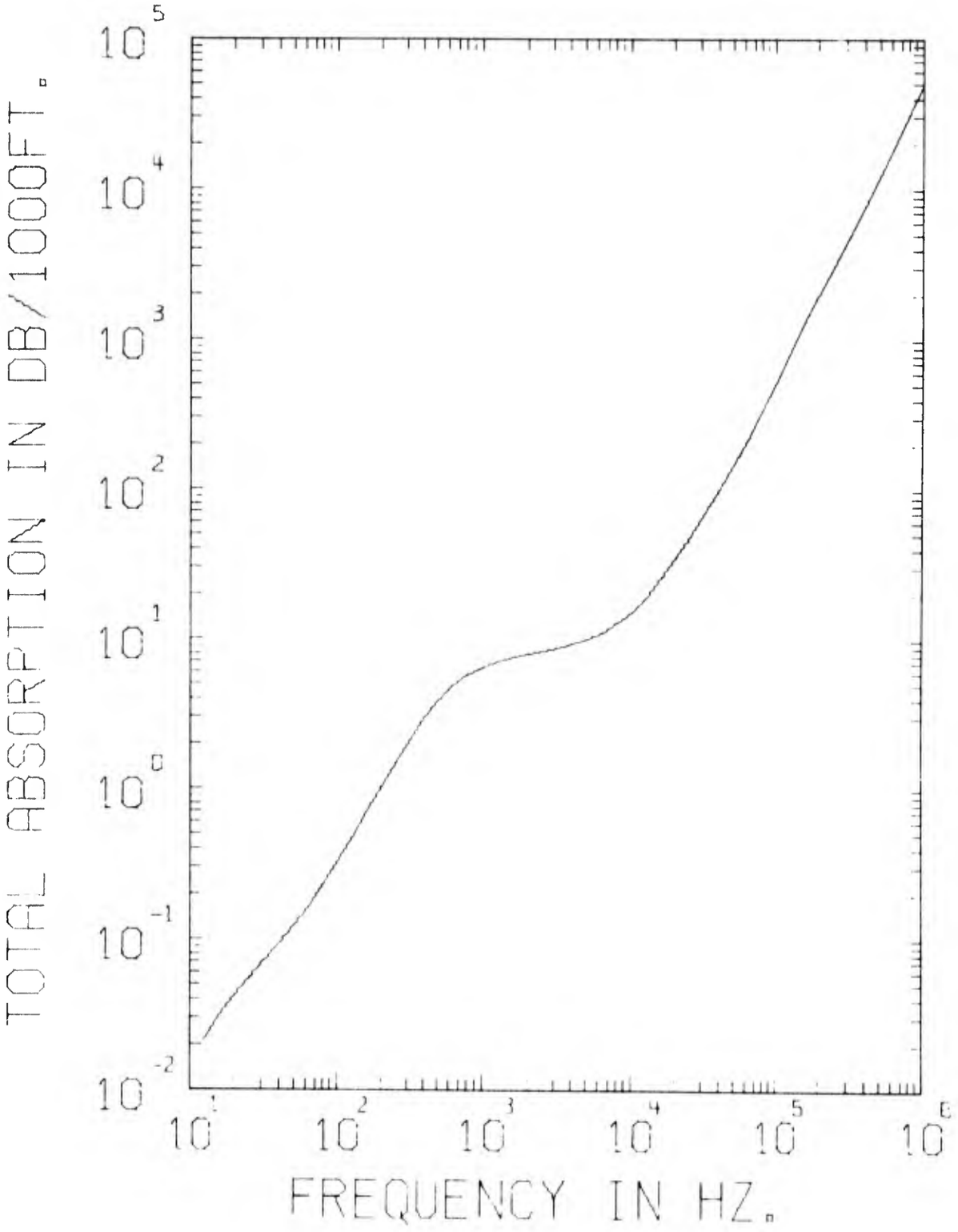


ABSORPTION AND VELOCITY OF SOUND IN STILL AIR

RELATIVE HUMIDITY = 1.0% TEMPERATURE = 68. DEGREES F

FREQUENCY (HZ)	ABSORPTION (DB/1000FT)	ABSORPTION (DB/KM)	ABSORPTION (DB/SEC)	VELOCITY (1000FT/SEC)
12.	0.026	0.08	0.029	1.126817
16.	0.039	0.13	0.044	1.126827
20.	0.053	0.17	0.060	1.126836
25.	0.071	0.23	0.080	1.126844
31.	0.094	0.31	0.105	1.126852
40.	0.132	0.43	0.149	1.126861
50.	0.182	0.60	0.206	1.126868
63.	0.260	0.85	0.293	1.126877
80.	0.380	1.25	0.428	1.126889
100.	0.543	1.78	0.612	1.126904
125.	0.771	2.53	0.869	1.126925
160.	1.109	3.64	1.250	1.126955
200.	1.490	4.89	1.679	1.126988
250.	1.921	6.30	2.165	1.127027
315.	2.381	7.81	2.683	1.127066
400.	2.822	9.26	3.181	1.127105
500.	3.173	10.41	3.576	1.127133
630.	3.462	11.35	3.902	1.127158
800.	3.689	12.10	4.158	1.127176
1000.	3.854	12.64	4.344	1.127189
1250.	3.994	13.10	4.502	1.127196
1600.	4.147	13.60	4.674	1.127201
2000.	4.310	14.14	4.859	1.127206
2500.	4.531	14.86	5.107	1.127208
3150.	4.864	15.95	5.483	1.127209
4000.	5.394	17.69	6.080	1.127210
5000.	6.155	20.19	6.938	1.127211
6300.	7.361	24.14	8.297	1.127213
8000.	9.277	30.43	10.457	1.127213
10000.	11.970	39.26	13.493	1.127214
12500.	15.911	52.19	17.936	1.127216
16000.	22.356	73.33	25.200	1.127218
20000.	30.916	101.41	34.850	1.127221
25000.	43.375	142.27	48.893	1.127222
31500.	62.618	205.39	70.584	1.127224
40000.	93.309	306.05	105.180	1.127225
50000.	137.853	452.16	155.391	1.127226
63000.	209.833	688.25	236.529	1.127227
80000.	329.377	1077.09	370.155	1.127227
100000.	503.565	1651.69	567.632	1.127228
125000.	777.061	2548.76	875.924	1.127228
160000.	1261.978	4138.96	1422.424	1.127228
200000.	1961.658	6434.24	2211.236	1.127228
250000.	3055.001	10020.40	3443.682	1.127228
315000.	4839.539	15873.68	5455.262	1.127228
400000.	7792.676	25559.97	8784.117	1.127228
500000.	12165.891	39904.12	13713.727	1.127228
630000.	19303.926	63316.87	21759.918	1.127228
800000.	31116.449	102061.94	35075.324	1.127228
1000000.	48609.227	159438.25	54793.668	1.127228

SOUND ABSORPTION IN STILL AIR FOR 2% RELATIVE HUMIDITY.

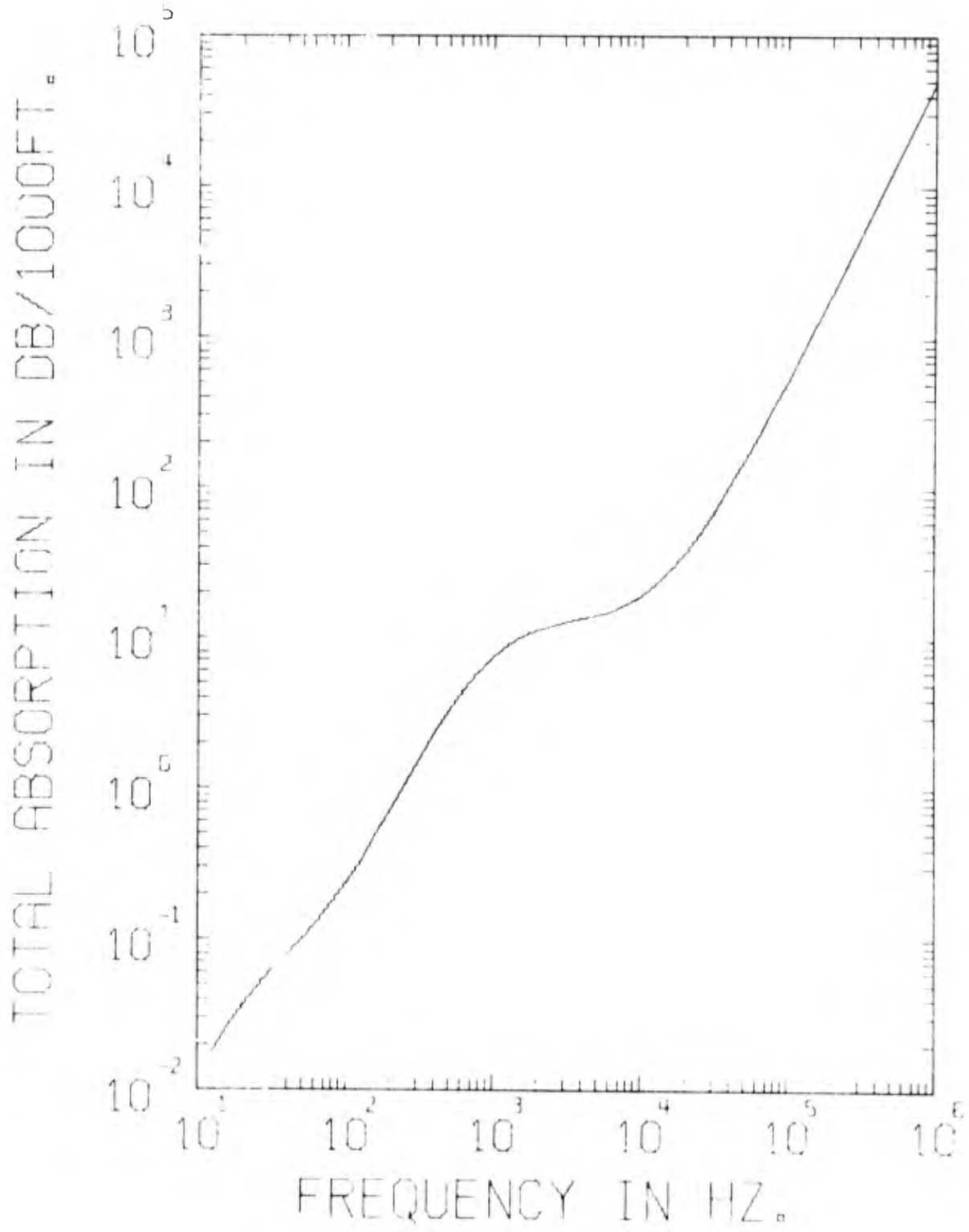


ABSORPTION AND VELOCITY OF SOUND IN STILL AIR

RELATIVE HUMIDITY = 2.0% TEMPERATURE = 68. DEGREES F

FREQUENCY (HZ)	ABSORPTION (DB/1000FT)	ABSORPTION (DB/KM)	ABSORPTION (DB/SEC)	VELOCITY (1000FT/SEC)
12.	0.020	0.07	0.023	1.126850
16.	0.031	0.10	0.035	1.126859
20.	0.042	0.14	0.047	1.126866
25.	0.055	0.18	0.062	1.126875
31.	0.070	0.23	0.079	1.126883
40.	0.094	0.31	0.106	1.126890
50.	0.122	0.40	0.138	1.126895
63.	0.164	0.54	0.185	1.126901
80.	0.231	0.76	0.260	1.126905
100.	0.325	1.07	0.367	1.126911
125.	0.468	1.53	0.527	1.126919
160.	0.707	2.32	0.797	1.126929
200.	1.028	3.37	1.159	1.126944
250.	1.479	4.85	1.667	1.126963
315.	2.106	6.91	2.374	1.126988
400.	2.927	9.60	3.298	1.127024
500.	3.811	12.50	4.296	1.127061
630.	4.770	15.65	5.376	1.127100
800.	5.707	18.72	6.433	1.127139
1000.	6.465	21.20	7.287	1.127171
1250.	7.083	23.23	7.983	1.127195
1600.	7.620	24.99	8.589	1.127214
2000.	8.014	26.29	9.034	1.127227
2500.	8.373	27.46	9.438	1.127235
3150.	8.771	28.77	9.887	1.127241
4000.	9.292	30.48	10.474	1.127246
5000.	9.981	32.74	11.251	1.127248
6300.	11.046	36.23	12.452	1.127250
8000.	12.756	41.84	14.379	1.127251
10000.	15.228	49.95	17.166	1.127252
12500.	18.998	62.31	21.415	1.127254
16000.	25.464	83.52	28.704	1.127255
20000.	34.416	112.88	38.795	1.127256
25000.	47.749	156.62	53.825	1.127258
31500.	68.403	224.36	77.108	1.127259
40000.	100.906	330.97	113.748	1.127262
50000.	147.197	482.81	165.930	1.127264
63000.	220.803	724.23	248.904	1.127266
80000.	340.695	1117.48	384.054	1.127267
100000.	516.817	1695.16	582.591	1.127269
125000.	790.975	2594.40	891.641	1.127268
160000.	1276.282	4186.20	1438.711	1.127268
200000.	1976.344	6482.40	2227.870	1.127269
250000.	3069.856	10069.13	3460.555	1.127269
315000.	4854.488	15922.72	5472.312	1.127269
400000.	7807.656	25609.11	8801.324	1.127269
500000.	12180.836	39953.14	13731.074	1.127269
630000.	19318.762	63365.53	21777.434	1.127269
800000.	31131.047	102109.81	35093.055	1.127269
1000000.	48623.480	159485.00	54811.730	1.127269

SOUND ABSORPTION IN STILL AIR FOR 3% RELATIVE HUMIDITY.

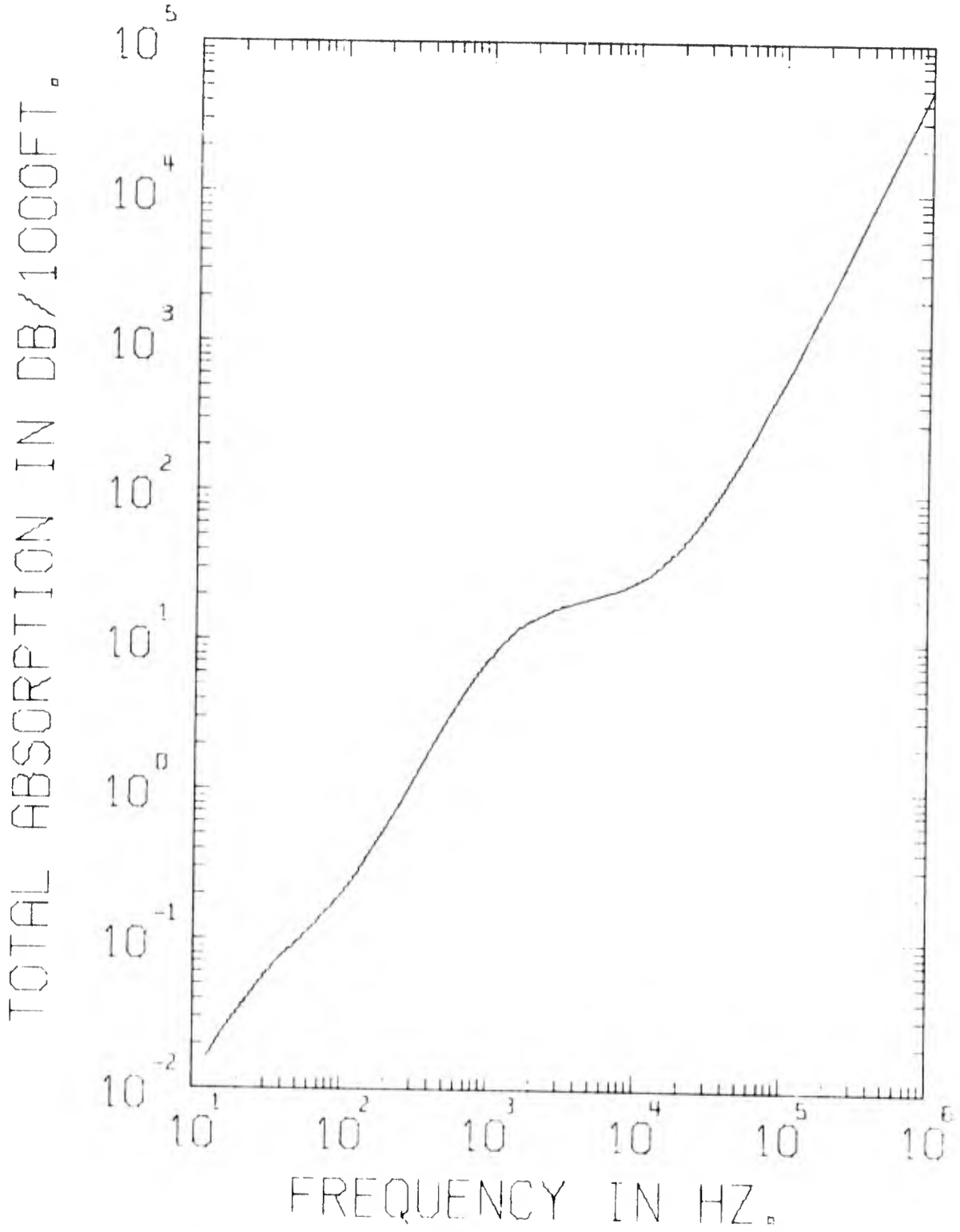


ABSORPTION AND VELOCITY OF SOUND IN STILL AIR

RELATIVE HUMIDITY = 3.0% TEMPERATURE = 68. DEGREES F

FREQUENCY (HZ)	ABSORPTION (DB/1000FT)	ABSORPTION (DB/KM)	ABSORPTION (DB/SEC)	VELOCITY (1000FT/SEC)
12.	0.017	0.06	0.019	1.126885
16.	0.027	0.09	0.030	1.126893
20.	0.037	0.12	0.041	1.126901
25.	0.049	0.16	0.055	1.126908
31.	0.063	0.21	0.071	1.126917
40.	0.082	0.27	0.092	1.126925
50.	0.103	0.34	0.116	1.126931
63.	0.133	0.44	0.150	1.126936
80.	0.177	0.58	0.200	1.126941
100.	0.239	0.79	0.270	1.126944
125.	0.334	1.09	0.376	1.126948
160.	0.496	1.63	0.559	1.126953
200.	0.722	2.37	0.814	1.126960
250.	1.060	3.48	1.195	1.126969
315.	1.575	5.16	1.775	1.126983
400.	2.338	7.67	2.635	1.127003
500.	3.305	10.84	3.725	1.127028
630.	4.568	14.98	5.148	1.127061
800.	6.090	19.98	6.864	1.127100
1000.	7.590	24.90	8.555	1.127139
1250.	9.027	29.61	10.175	1.127175
1600.	10.417	34.17	11.742	1.127212
2000.	11.449	37.55	12.904	1.127236
2500.	12.290	40.31	13.854	1.127254
3150.	13.035	42.75	14.694	1.127267
4000.	13.779	45.19	15.532	1.127276
5000.	14.574	47.80	16.429	1.127282
6300.	15.662	51.37	17.656	1.127286
8000.	17.311	56.78	19.515	1.127290
10000.	19.554	64.46	22.155	1.127291
12500.	23.228	76.19	26.185	1.127292
16000.	29.439	96.56	33.187	1.127294
20000.	38.206	125.32	43.070	1.127295
25000.	51.540	169.05	58.101	1.127296
31500.	72.583	238.07	81.823	1.127298
40000.	106.066	347.90	119.568	1.127300
50000.	153.794	504.44	173.372	1.127301
63000.	229.214	751.82	258.393	1.127303
80000.	351.010	1151.31	395.696	1.127306
100000.	528.698	1734.13	596.005	1.127307
125000.	804.106	2637.47	906.475	1.127308
160000.	1290.417	4232.57	1454.698	1.127309
200000.	1991.099	6530.80	2244.585	1.127310
250000.	3085.031	10118.90	3477.796	1.127310
315000.	4869.926	15973.35	5489.914	1.127310
400000.	7823.238	25660.22	8819.211	1.127310
500000.	12196.473	40004.43	13749.203	1.127310
630000.	19334.352	63416.66	21795.801	1.127310
800000.	31146.480	102160.44	35111.730	1.127310
1000000.	48638.613	159534.62	54830.785	1.127310

SOUND ABSORPTION IN STILL AIR FOR 4% RELATIVE HUMIDITY.

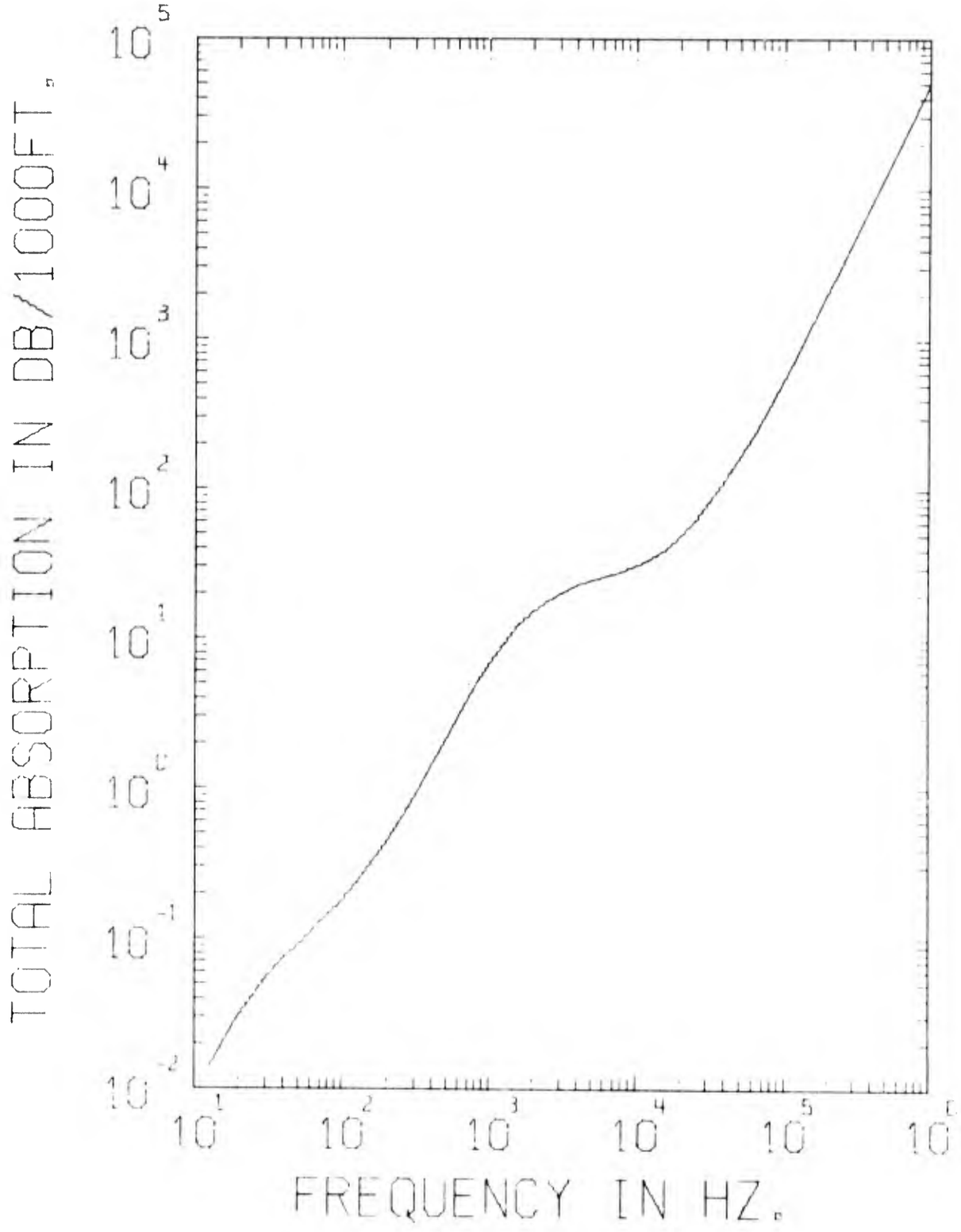


ABSORPTION AND VELOCITY OF SOUND IN STILL AIR

RELATIVE HUMIDITY = 4.0% TEMPERATURE = 68. DEGREES F

FREQUENCY (HZ)	ABSORPTION (DB/1000FT)	ABSORPTION (DB/KM)	ABSORPTION (DB/SEC)	VELOCITY (1000FT/SEC)
12.	0.015	0.05	0.017	1.126923
16.	0.024	0.08	0.027	1.126929
20.	0.033	0.11	0.038	1.126936
25.	0.045	0.15	0.051	1.126944
31.	0.059	0.19	0.066	1.126951
40.	0.077	0.25	0.087	1.126961
50.	0.096	0.31	0.108	1.126967
63.	0.120	0.39	0.135	1.126972
80.	0.154	0.50	0.173	1.126978
100.	0.200	0.65	0.225	1.126981
125.	0.268	0.88	0.302	1.126985
160.	0.385	1.26	0.434	1.126987
200.	0.551	1.81	0.621	1.126992
250.	0.803	2.63	0.905	1.126996
315.	1.200	3.93	1.352	1.127004
400.	1.820	5.97	2.051	1.127015
500.	2.664	8.74	3.003	1.127031
630.	3.881	12.73	4.374	1.127053
800.	5.548	18.20	6.254	1.127083
1000.	7.452	24.44	8.400	1.127119
1250.	9.573	31.40	10.790	1.127156
1600.	11.950	39.19	13.470	1.127198
2000.	13.929	45.69	15.701	1.127234
2500.	15.634	51.28	17.623	1.127261
3150.	17.102	56.10	19.279	1.127285
4000.	18.392	60.33	20.733	1.127302
5000.	19.529	64.06	22.016	1.127314
6300.	20.832	68.33	23.484	1.127320
8000.	22.580	74.06	25.455	1.127326
10000.	24.920	81.74	28.093	1.127329
12500.	28.409	93.18	32.026	1.127332
16000.	34.436	112.95	38.821	1.127333
20000.	42.980	140.97	48.453	1.127334
25000.	56.095	183.99	63.238	1.127336
31500.	77.042	252.70	86.852	1.127337
40000.	110.771	363.33	124.876	1.127339
50000.	159.230	522.27	179.506	1.127341
63000.	235.977	774.00	266.026	1.127343
80000.	359.591	1179.46	405.383	1.127345
100000.	539.097	1768.24	607.749	1.127346
125000.	816.176	2677.06	920.115	1.127349
160000.	1303.986	4277.07	1470.048	1.127350
200000.	2005.672	6578.60	2261.094	1.127350
250000.	3100.310	10169.02	3495.137	1.127351
315000.	4885.695	16025.08	5507.891	1.127351
400000.	7839.312	25712.94	8837.652	1.127351
500000.	12212.672	40057.56	13767.977	1.127352
630000.	19350.574	63469.87	21814.902	1.127352
800000.	31162.605	102213.31	35131.215	1.127352
1000000.	48654.492	159586.69	54850.727	1.127352

SOUND ABSORPTION IN STILL AIR FOR 5% RELATIVE HUMIDITY.

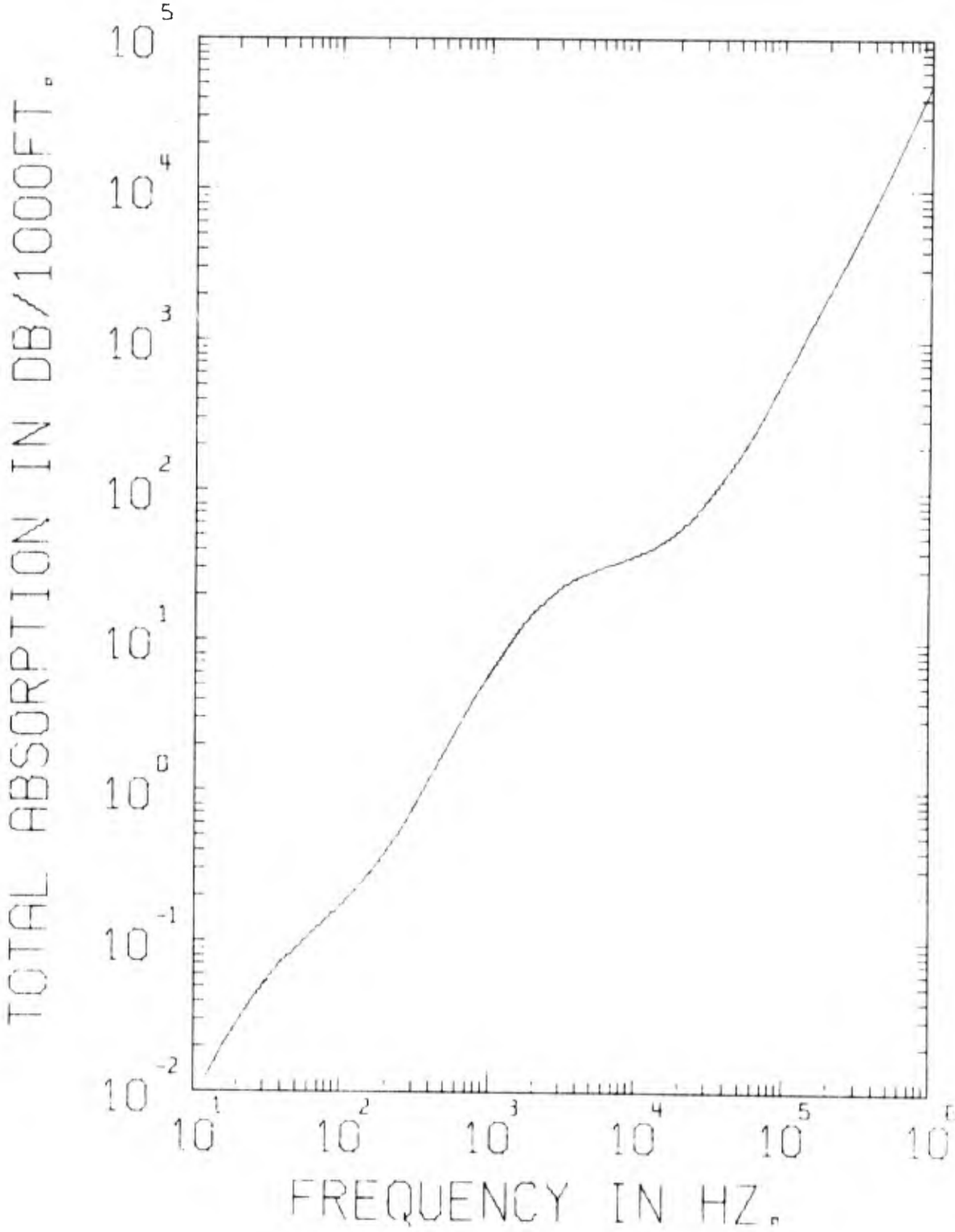


ABSORPTION AND VELOCITY OF SOUND IN STILL AIR

RELATIVE HUMIDITY = 5.0% TEMPERATURE = 68. DEGREES F

FREQUENCY (HZ)	ABSORPTION (DB/1000FT)	ABSORPTION (DB/KM)	ABSORPTION (DB/SEC)	VELOCITY (1000FT/SEC)
12.	0.013	0.04	0.015	1.126963
16.	0.021	0.07	0.024	1.126967
20.	0.031	0.10	0.034	1.126973
25.	0.042	0.14	0.048	1.126980
31.	0.056	0.18	0.063	1.126987
40.	0.074	0.24	0.083	1.126996
50.	0.092	0.30	0.104	1.127004
63.	0.114	0.37	0.129	1.127009
80.	0.143	0.47	0.161	1.127015
100.	0.179	0.59	0.202	1.127019
125.	0.232	0.76	0.262	1.127022
160.	0.322	1.06	0.363	1.127025
200.	0.449	1.47	0.506	1.127028
250.	0.644	2.11	0.726	1.127031
315.	0.954	3.13	1.075	1.127035
400.	1.451	4.76	1.635	1.127043
500.	2.151	7.05	2.424	1.127052
630.	3.211	10.53	3.619	1.127067
800.	4.774	15.66	5.380	1.127088
1000.	6.732	22.09	7.588	1.127115
1250.	9.164	30.06	10.329	1.127147
1600.	12.259	40.21	13.818	1.127189
2000.	15.175	49.77	17.106	1.127228
2500.	17.945	58.86	20.229	1.127263
3150.	20.476	67.16	23.082	1.127295
4000.	22.685	74.41	25.573	1.127321
5000.	24.473	80.27	27.589	1.127338
6300.	26.245	86.08	29.587	1.127352
8000.	28.295	92.81	31.899	1.127360
10000.	30.781	100.96	34.701	1.127365
12500.	34.306	112.52	38.676	1.127369
16000.	40.263	132.06	45.391	1.127372
20000.	48.653	159.58	54.850	1.127373
25000.	61.552	201.89	69.393	1.127375
31500.	82.274	269.86	92.753	1.127376
40000.	115.903	380.16	130.666	1.127378
50000.	164.582	539.83	185.547	1.127379
63000.	242.070	793.99	272.905	1.127381
80000.	367.063	1203.97	413.821	1.127383
100000.	548.273	1798.34	618.115	1.127386
125000.	827.179	2713.15	932.552	1.127389
160000.	1316.839	4319.23	1484.590	1.127389
200000.	2019.879	6625.20	2277.191	1.127390
250000.	3115.528	10218.93	3512.417	1.127391
315000.	4901.645	16077.39	5526.066	1.127391
400000.	7855.758	25766.88	8856.508	1.127391
500000.	12229.379	40112.36	13787.301	1.127392
630000.	19367.410	63525.10	21834.656	1.127392
800000.	31179.379	102268.31	35151.375	1.127392
1000000.	48671.082	159641.12	54871.379	1.127392

SOUND ABSORPTION IN STILL AIR FOR 6% RELATIVE HUMIDITY.

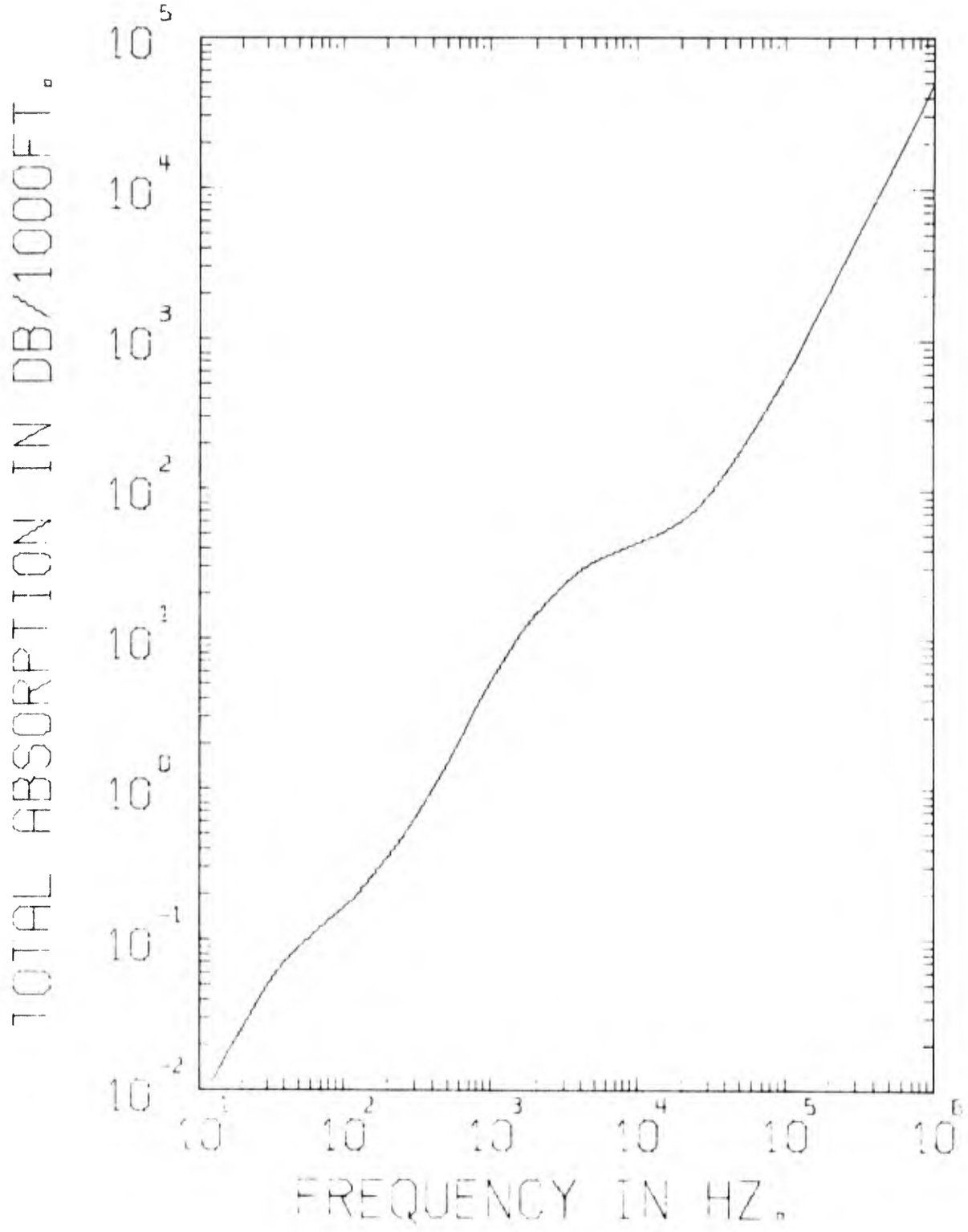


ABSORPTION AND VELOCITY OF SOUND IN STILL AIR

RELATIVE HUMIDITY = 6.0% TEMPERATURE = 68. DEGREES F

FREQUENCY (HZ)	ABSORPTION (DB/1000FT)	ABSORPTION (DB/KM)	ABSORPTION (DB/SEC)	VELOCITY (1000FT/SEC)
12.	0.012	0.04	0.013	1.127002
16.	0.020	0.06	0.022	1.127006
20.	0.028	0.09	0.032	1.127010
25.	0.040	0.13	0.045	1.127016
31.	0.053	0.17	0.060	1.127024
40.	0.072	0.24	0.081	1.127032
50.	0.090	0.30	0.102	1.127040
63.	0.112	0.37	0.126	1.127048
80.	0.139	0.45	0.155	1.127053
100.	0.169	0.55	0.190	1.127057
125.	0.213	0.70	0.240	1.127060
160.	0.285	0.93	0.321	1.127064
200.	0.386	1.27	0.435	1.127066
250.	0.541	1.78	0.610	1.127069
315.	0.790	2.59	0.891	1.127072
400.	1.193	3.91	1.345	1.127076
500.	1.771	5.81	1.996	1.127083
630.	2.671	8.76	3.011	1.127092
800.	4.053	13.29	4.568	1.127107
1000.	5.886	19.31	6.634	1.127127
1250.	8.333	27.33	9.393	1.127152
1600.	11.756	38.56	13.251	1.127189
2000.	15.338	50.31	17.290	1.127226
2500.	19.096	62.63	21.526	1.127265
3150.	22.833	74.89	25.739	1.127302
4000.	26.270	86.17	29.615	1.127336
5000.	29.038	95.24	32.736	1.127360
6300.	31.591	103.62	35.615	1.127378
8000.	34.204	112.19	38.561	1.127392
10000.	37.023	121.43	41.739	1.127400
12500.	40.730	133.60	45.920	1.127405
16000.	46.744	153.32	52.700	1.127410
20000.	55.074	180.64	62.091	1.127412
25000.	67.824	222.46	76.465	1.127414
31500.	88.324	289.70	99.578	1.127417
40000.	121.736	399.29	137.248	1.127418
50000.	170.364	558.79	192.072	1.127419
63000.	248.154	813.94	279.774	1.127420
80000.	374.034	1226.83	421.694	1.127422
100000.	556.627	1825.74	627.556	1.127425
125000.	837.279	2746.27	943.971	1.127427
160000.	1328.949	4358.95	1498.296	1.127429
200000.	2033.610	6670.24	2292.753	1.127430
250000.	3130.559	10268.23	3529.489	1.127431
315000.	4917.652	16129.89	5544.316	1.127432
400000.	7872.453	25821.64	8875.652	1.127432
500000.	12246.473	40168.43	13807.086	1.127434
630000.	19384.723	63581.33	21854.988	1.127434
800000.	31196.738	102325.25	35172.254	1.127434
1000000.	48688.320	159697.62	54892.855	1.127434

SOUND ABSORPTION IN STILL AIR FOR 7% RELATIVE HUMIDITY.

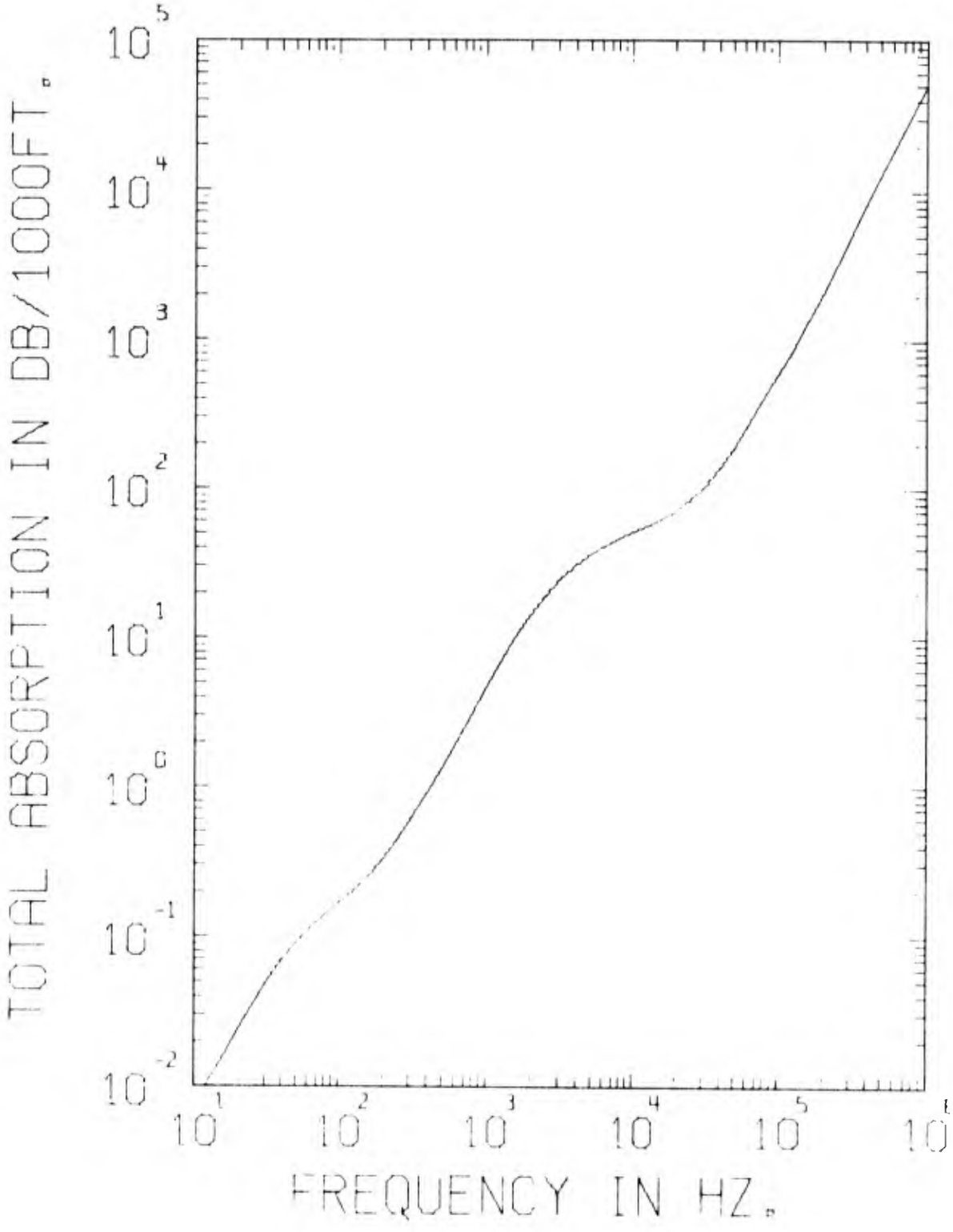


ABSORPTION AND VELOCITY OF SOUND IN STILL AIR

RELATIVE HUMIDITY = 7.0% TEMPERATURE = 68. DEGREES F

FREQUENCY (HZ)	ABSORPTION (DB/1000FT)	ABSORPTION (DB/KM)	ABSORPTION (DB/SEC)	VELOCITY (1000FT/SEC)
12.	0.011	0.03	0.012	1.127041
16.	0.018	0.06	0.020	1.127044
20.	0.026	0.09	0.029	1.127048
25.	0.037	0.12	0.042	1.127053
31.	0.051	0.17	0.057	1.127061
40.	0.070	0.23	0.079	1.127069
50.	0.089	0.29	0.100	1.127077
63.	0.110	0.36	0.124	1.127085
80.	0.135	0.44	0.152	1.127091
100.	0.164	0.54	0.184	1.127097
125.	0.201	0.66	0.227	1.127100
160.	0.262	0.86	0.295	1.127103
200.	0.345	1.13	0.389	1.127106
250.	0.473	1.55	0.533	1.127108
315.	0.677	2.22	0.764	1.127110
400.	1.010	3.31	1.139	1.127113
500.	1.493	4.90	1.683	1.127117
630.	2.256	7.40	2.543	1.127124
800.	3.456	11.34	3.896	1.127134
1000.	5.105	16.74	5.754	1.127149
1250.	7.413	24.31	8.355	1.127169
1600.	10.861	35.63	12.243	1.127198
2000.	14.775	48.46	16.655	1.127231
2500.	19.249	63.14	21.699	1.127269
3150.	24.099	79.05	27.167	1.127309
4000.	28.897	94.78	32.577	1.127347
5000.	32.911	107.95	37.104	1.127378
6300.	36.569	119.95	41.228	1.127402
8000.	40.049	131.36	45.152	1.127421
10000.	43.433	142.46	48.968	1.127433
12500.	47.503	155.81	53.557	1.127441
16000.	53.727	176.22	60.574	1.127447
20000.	62.105	203.70	70.020	1.127451
25000.	74.789	245.31	84.321	1.127454
31500.	95.125	312.01	107.249	1.127456
40000.	128.309	420.85	144.663	1.127457
50000.	176.766	579.79	199.296	1.127459
63000.	254.588	835.05	287.038	1.127460
80000.	380.952	1249.52	429.509	1.127462
100000.	564.556	1851.74	636.517	1.127464
125000.	846.723	2777.25	954.651	1.127466
160000.	1340.390	4396.48	1511.248	1.127469
200000.	2046.828	6713.59	2307.740	1.127471
250000.	3145.312	10316.62	3546.250	1.127472
315000.	4933.645	16182.35	5562.547	1.127473
400000.	7889.352	25877.07	8895.027	1.127473
500000.	12263.934	40225.70	13827.262	1.127474
630000.	19402.508	63640.22	21875.816	1.127474
800000.	31214.664	102384.06	35193.715	1.127474
1000000.	48706.199	159756.31	54914.965	1.127474

SOUND ABSORPTION IN STILL AIR FOR 8% RELATIVE HUMIDITY.

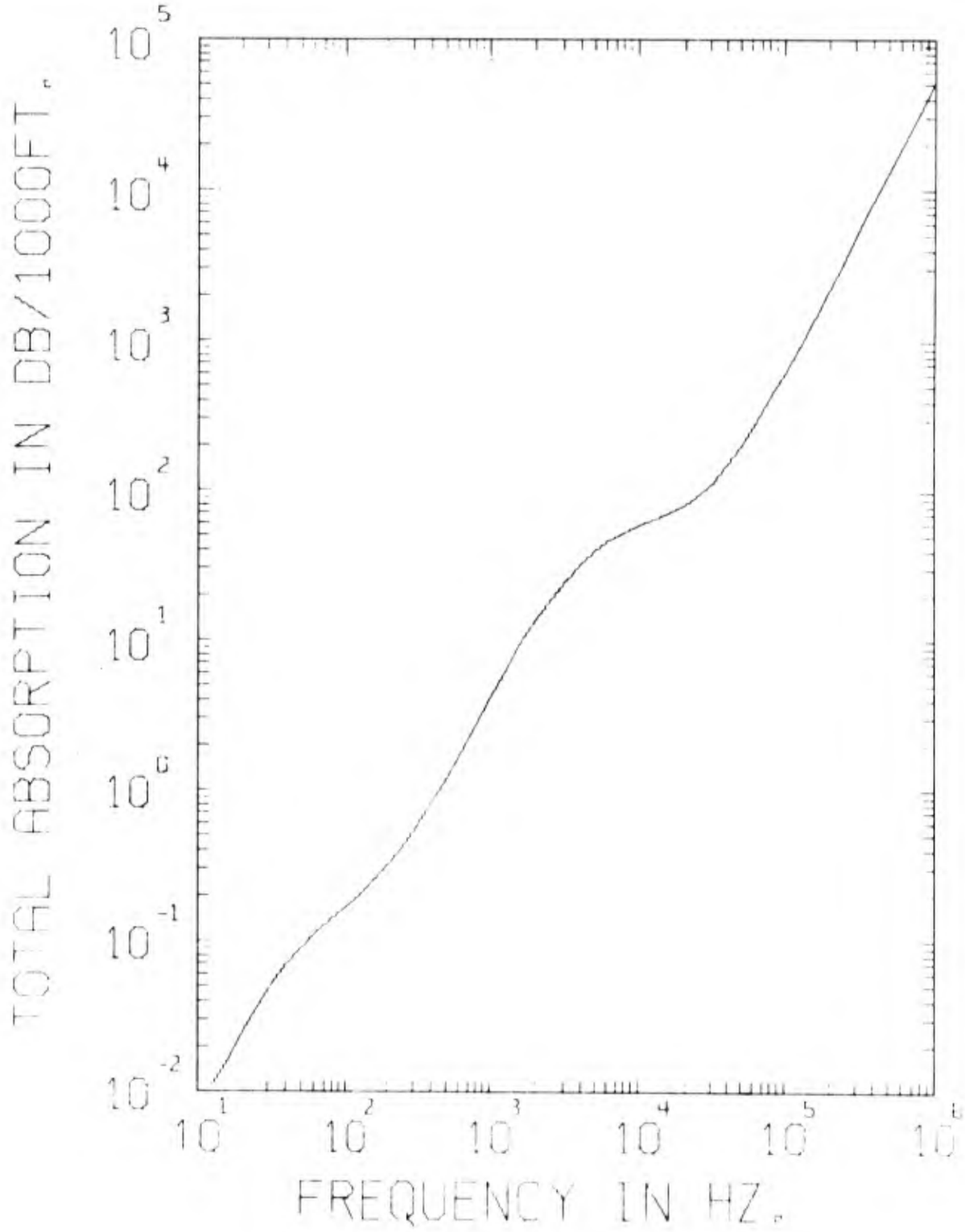


ABSORPTION AND VELOCITY OF SOUND IN STILL AIR

RELATIVE HUMIDITY = 8.0% TEMPERATURE = 68. DEGREES F

FREQUENCY (HZ)	ABSORPTION (DB/1000FT)	ABSORPTION (DB/KM)	ABSORPTION (DB/SEC)	VELOCITY (1000FT/SEC)
12.	0.010	0.03	0.011	1.127080
16.	0.016	0.05	0.019	1.127084
20.	0.024	0.08	0.027	1.127088
25.	0.035	0.12	0.040	1.127092
31.	0.048	0.16	0.055	1.127099
40.	0.068	0.22	0.076	1.127108
50.	0.087	0.29	0.098	1.127115
63.	0.109	0.36	0.123	1.127122
80.	0.134	0.44	0.151	1.127130
100.	0.161	0.53	0.182	1.127135
125.	0.195	0.64	0.220	1.127139
160.	0.248	0.81	0.279	1.127143
200.	0.319	1.04	0.359	1.127145
250.	0.426	1.40	0.480	1.127147
315.	0.598	1.96	0.674	1.127148
400.	0.878	2.88	0.990	1.127151
500.	1.286	4.22	1.450	1.127154
630.	1.938	6.36	2.185	1.127159
800.	2.979	9.77	3.358	1.127167
1000.	4.440	14.56	5.005	1.127177
1250.	6.551	21.49	7.384	1.127192
1600.	9.853	32.32	11.106	1.127215
2000.	13.831	45.36	15.590	1.127244
2500.	18.703	61.35	21.083	1.127278
3150.	24.407	80.05	27.514	1.127318
4000.	30.494	100.02	34.378	1.127358
5000.	35.889	117.71	40.461	1.127393
6300.	40.918	134.21	46.132	1.127424
8000.	45.583	149.51	51.392	1.127448
10000.	49.799	163.34	56.146	1.127464
12500.	54.448	178.59	61.389	1.127476
16000.	61.066	200.30	68.851	1.127484
20000.	69.618	228.35	78.494	1.127489
25000.	82.336	270.06	92.833	1.127492
31500.	102.594	336.47	115.663	1.127496
40000.	135.579	444.70	152.866	1.127498
50000.	183.833	602.97	207.271	1.127499
63000.	261.542	857.86	294.888	1.127501
80000.	388.102	1272.97	437.586	1.127502
100000.	572.376	1877.39	645.357	1.127505
125000.	855.766	2806.91	964.881	1.127506
160000.	1351.284	4432.21	1523.585	1.127509
200000.	2059.561	6755.36	2322.175	1.127510
250000.	3159.747	10363.96	3562.655	1.127513
315000.	4949.543	16234.50	5580.672	1.127513
400000.	7906.352	25932.83	8914.520	1.127514
500000.	12281.637	40283.76	13847.727	1.127515
630000.	19420.684	63699.84	21897.105	1.127515
800000.	31233.098	102444.50	35215.777	1.127515
1000000.	48724.590	159816.62	54937.695	1.127515

SOUND ABSORPTION IN STILL AIR FOR 9% RELATIVE HUMIDITY.

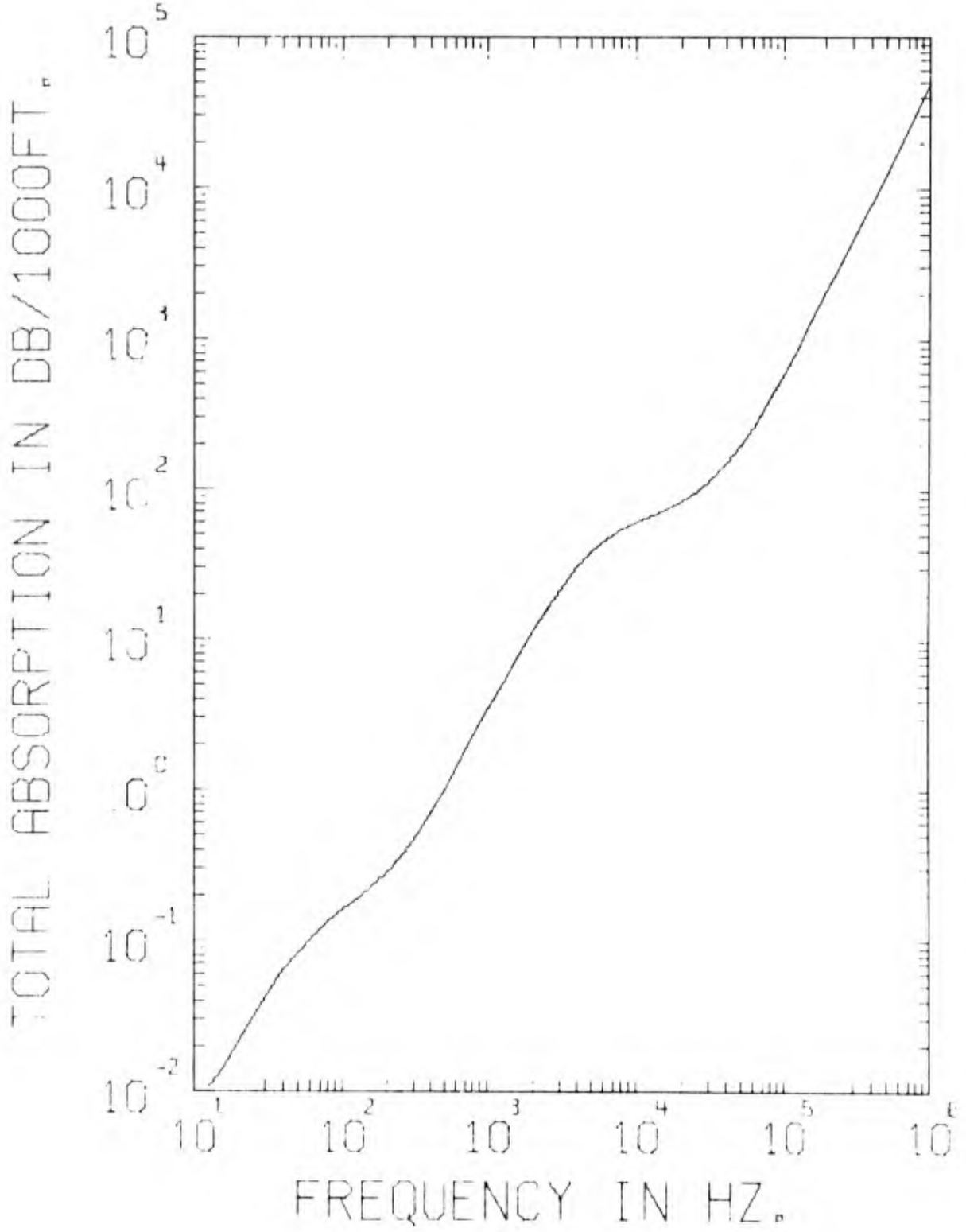


ABSORPTION AND VELOCITY OF SOUND IN STILL AIR

RELATIVE HUMIDITY = 9.0% TEMPERATURE = 68. DEGREES F

FREQUENCY (HZ)	ABSORPTION (DB/1000FT)	ABSORPTION (DB/KM)	ABSORPTION (DB/SEC)	VELOCITY (1000FT/SEC)
12.	0.009	0.03	0.010	1.127121
16.	0.015	0.05	0.017	1.127124
20.	0.023	0.07	0.026	1.127127
25.	0.033	0.11	0.037	1.127131
31.	0.046	0.15	0.052	1.127137
40.	0.066	0.22	0.074	1.127145
50.	0.086	0.28	0.097	1.127152
63.	0.109	0.36	0.123	1.127161
80.	0.134	0.44	0.151	1.127169
100.	0.160	0.53	0.181	1.127174
125.	0.192	0.63	0.216	1.127178
160.	0.239	0.78	0.269	1.127183
200.	0.301	0.99	0.339	1.127185
250.	0.393	1.29	0.443	1.127187
315.	0.540	1.77	0.609	1.127189
400.	0.780	2.56	0.879	1.127190
500.	1.130	3.71	1.274	1.127193
630.	1.693	5.55	1.908	1.127196
800.	2.600	8.53	2.931	1.127202
1000.	3.892	12.76	4.387	1.127211
1250.	5.797	19.01	6.534	1.127221
1600.	8.873	29.11	10.003	1.127239
2000.	12.745	41.80	14.367	1.127263
2500.	17.747	58.21	20.006	1.127294
3150.	23.992	78.69	27.047	1.127330
4000.	31.144	102.15	35.111	1.127371
5000.	37.893	124.29	42.721	1.127408
6300.	44.454	145.81	50.120	1.127444
8000.	50.582	165.91	57.030	1.127473
10000.	55.910	183.39	63.038	1.127494
12500.	61.387	201.35	69.215	1.127508
16000.	68.615	225.06	77.365	1.127521
20000.	77.492	254.17	87.374	1.127526
25000.	90.359	296.38	101.882	1.127531
31500.	110.609	362.80	124.715	1.127534
40000.	143.479	470.61	161.779	1.127538
50000.	191.543	628.26	215.972	1.127539
63000.	269.075	882.56	303.393	1.127541
80000.	395.645	1297.71	446.106	1.127542
100000.	580.315	1903.43	654.331	1.127544
125000.	864.632	2835.99	974.913	1.127547
160000.	1361.782	4466.64	1535.476	1.127549
200000.	2071.855	6795.68	2336.122	1.127551
250000.	3173.851	10410.23	3578.682	1.127552
315000.	4965.270	16286.08	5598.612	1.127553
400000.	7923.391	25988.72	8934.055	1.127555
500000.	12299.555	40342.54	13868.434	1.127556
630000.	19439.195	63760.55	21918.777	1.127556
800000.	31251.953	102536.37	35238.320	1.127556
1000000.	48743.488	159878.62	54961.051	1.127557

SOUND ABSORPTION IN STILL AIR FOR 10% RELATIVE HUMIDITY.

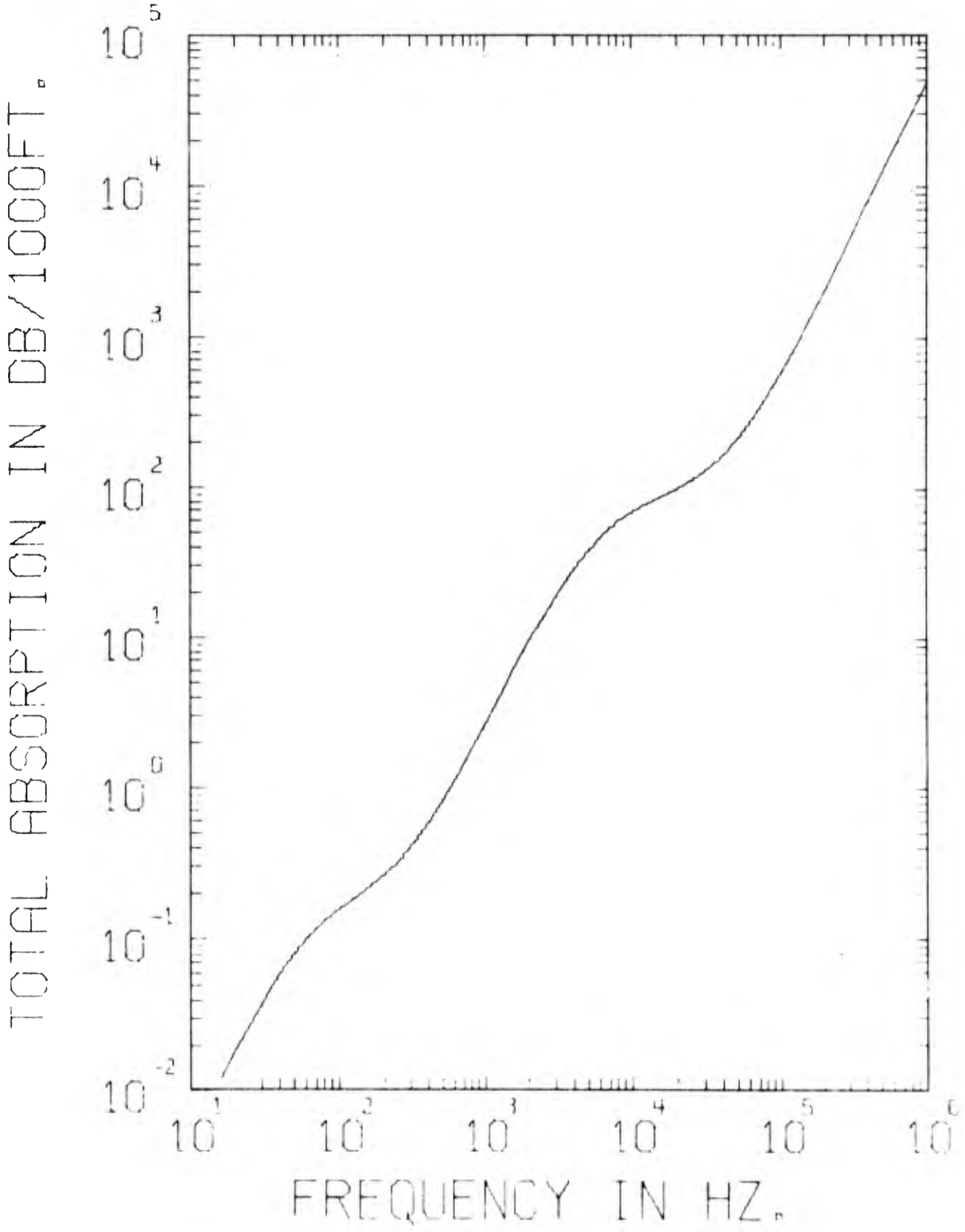


ABSORPTION AND VELOCITY OF SOUND IN STILL AIR

RELATIVE HUMIDITY = 10.0% TEMPERATURE = 68. DEGREES F

FREQUENCY (HZ)	ABSORPTION (DB/1000FT)	ABSORPTION (DB/KM)	ABSORPTION (DB/SEC)	VELOCITY (1000FT/SEC)
12.	0.008	0.03	0.009	1.127161
16.	0.014	0.05	0.016	1.127163
20.	0.021	0.07	0.024	1.127167
25.	0.031	0.10	0.035	1.127170
31.	0.044	0.14	0.050	1.127175
40.	0.064	0.21	0.072	1.127183
50.	0.084	0.28	0.095	1.127191
63.	0.108	0.35	0.122	1.127199
80.	0.134	0.44	0.151	1.127207
100.	0.161	0.53	0.181	1.127213
125.	0.191	0.63	0.215	1.127217
160.	0.234	0.77	0.264	1.127221
200.	0.289	0.95	0.326	1.127225
250.	0.370	1.21	0.417	1.127227
315.	0.498	1.63	0.561	1.127228
400.	0.706	2.32	0.796	1.127230
500.	1.011	3.32	1.139	1.127233
630.	1.501	4.92	1.692	1.127234
800.	2.297	7.54	2.590	1.127238
1000.	3.442	11.29	3.880	1.127245
1250.	5.155	16.91	5.811	1.127254
1600.	7.984	26.19	9.000	1.127269
2000.	11.658	38.24	13.141	1.127287
2500.	16.602	54.45	18.716	1.127313
3150.	23.104	75.78	26.046	1.127346
4000.	31.023	101.76	34.975	1.127386
5000.	38.967	127.81	43.932	1.127424
6300.	47.085	154.44	53.087	1.127462
8000.	54.875	179.99	61.872	1.127497
10000.	61.578	201.98	69.431	1.127522
12500.	68.146	223.52	76.837	1.127540
16000.	76.231	250.04	85.955	1.127555
20000.	85.605	280.78	96.525	1.127563
25000.	98.754	323.91	111.352	1.127570
31500.	119.113	390.69	134.309	1.127573
40000.	151.938	498.36	171.321	1.127576
50000.	199.852	655.52	225.349	1.127579
63000.	277.191	909.19	312.555	1.127581
80000.	403.662	1324.01	455.162	1.127583
100000.	598.526	1930.37	663.613	1.127584
125000.	873.505	2865.10	984.953	1.127587
160000.	1372.027	4500.25	1547.082	1.127589
200000.	2083.789	6834.82	2349.661	1.127591
250000.	3187.622	10455.40	3594.337	1.127592
315000.	4980.809	16337.05	5616.328	1.127594
400000.	7940.414	26044.55	8953.578	1.127596
500000.	12317.617	40401.78	13889.293	1.127596
630000.	19457.973	63822.14	21940.746	1.127597
800000.	31271.176	102569.44	35261.277	1.127597
1000000.	48762.930	159942.37	54984.926	1.127597

SOUND ABSORPTION IN STILL AIR FOR 12% RELATIVE HUMIDITY.

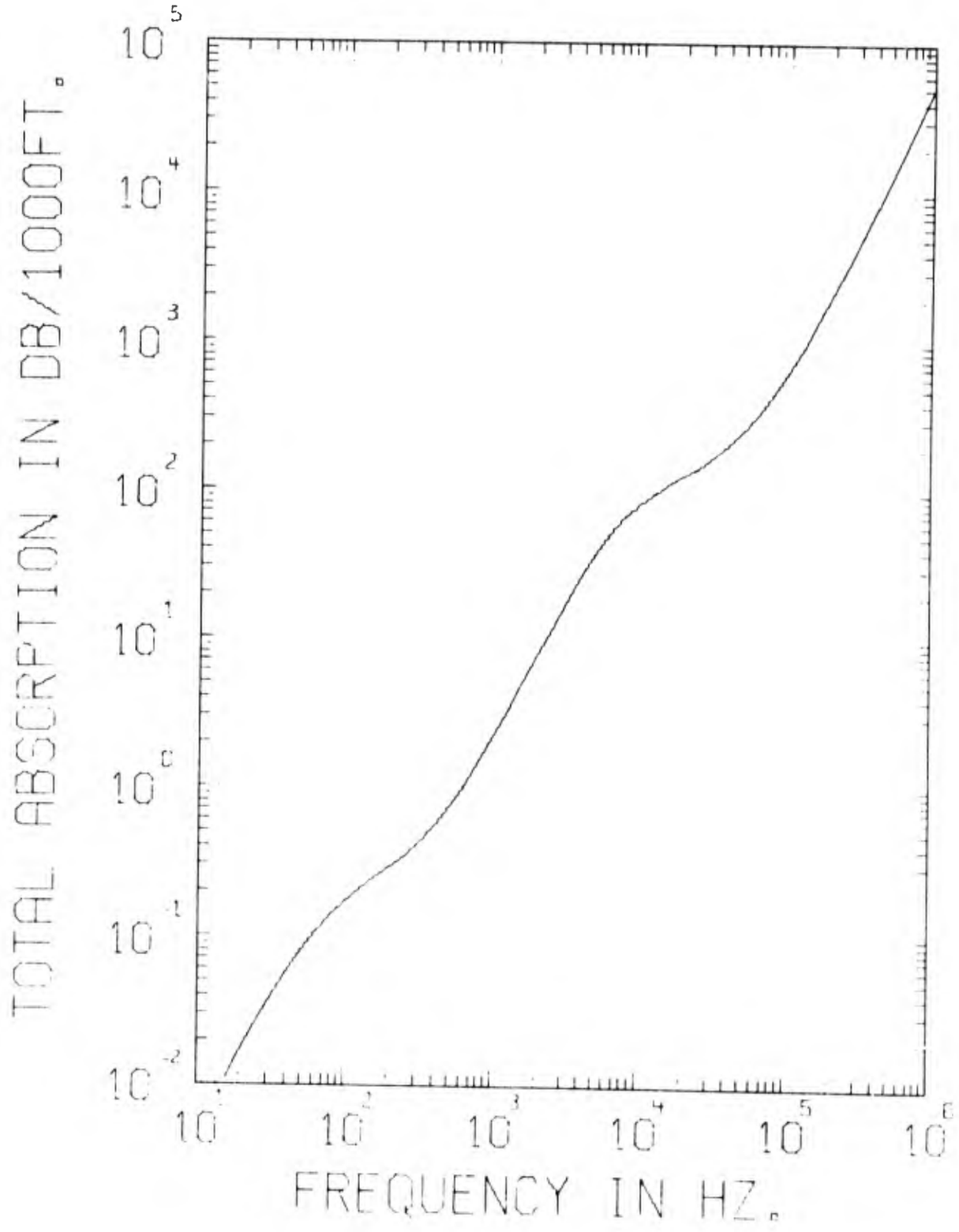


ABSORPTION AND VELOCITY OF SOUND IN STILL AIR

RELATIVE HUMIDITY = 12.0% TEMPERATURE = 68. DEGREES F

FREQUENCY (HZ)	ABSORPTION (DB/1000FT)	ABSORPTION (DB/KM)	ABSORPTION (DB/SEC)	VELOCITY (1000FT/SEC)
12.	0.007	0.02	0.008	1.127241
16.	0.012	0.04	0.014	1.127244
20.	0.019	0.06	0.021	1.127246
25.	0.028	0.09	0.032	1.127249
31.	0.040	0.13	0.045	1.127254
40.	0.060	0.20	0.067	1.127260
50.	0.081	0.26	0.091	1.127268
63.	0.106	0.35	0.120	1.127275
80.	0.134	0.44	0.151	1.127284
100.	0.162	0.53	0.183	1.127291
125.	0.192	0.63	0.216	1.127296
160.	0.231	0.76	0.260	1.127301
200.	0.277	0.91	0.312	1.127304
250.	0.342	1.12	0.386	1.127307
315.	0.443	1.45	0.500	1.127308
400.	0.606	1.99	0.683	1.127311
500.	0.844	2.77	0.952	1.127312
630.	1.229	4.03	1.385	1.127314
800.	1.857	6.09	2.093	1.127316
1000.	2.770	9.09	3.123	1.127320
1250.	4.161	13.65	4.690	1.127325
1600.	6.522	21.39	7.352	1.127336
2000.	9.714	31.86	10.951	1.127347
2500.	14.251	46.74	16.066	1.127365
3150.	20.674	67.81	23.308	1.127390
4000.	29.276	96.03	33.007	1.127423
5000.	38.859	127.46	43.812	1.127460
6300.	49.694	163.00	56.030	1.127501
8000.	60.972	199.99	68.748	1.127541
10000.	70.992	232.85	80.048	1.127573
12500.	80.485	263.99	90.755	1.127600
16000.	91.091	298.78	102.716	1.127621
20000.	102.069	334.79	115.096	1.127634
25000.	116.261	381.33	131.100	1.127644
31500.	137.214	450.06	154.730	1.127651
40000.	170.237	558.38	191.969	1.127656
50000.	218.040	715.17	245.875	1.127659
63000.	295.068	967.82	332.737	1.127661
80000.	421.212	1381.58	474.985	1.127663
100000.	606.083	1987.95	683.459	1.127666
125000.	891.771	2925.01	1005.621	1.127667
160000.	1392.281	4566.68	1570.032	1.127669
200000.	2106.940	6910.76	2375.936	1.127671
250000.	3214.324	10542.98	3624.710	1.127674
315000.	5011.270	16436.96	5651.082	1.127675
400000.	7974.289	26155.66	8992.422	1.127677
500000.	12354.000	40521.11	13931.320	1.127677
630000.	19496.242	63947.67	21985.480	1.127678
800000.	31310.672	102698.94	35308.383	1.127679
1000000.	48803.070	160074.00	55034.187	1.127679

SOUND ABSORPTION IN STILL AIR FOR 15% RELATIVE HUMIDITY.

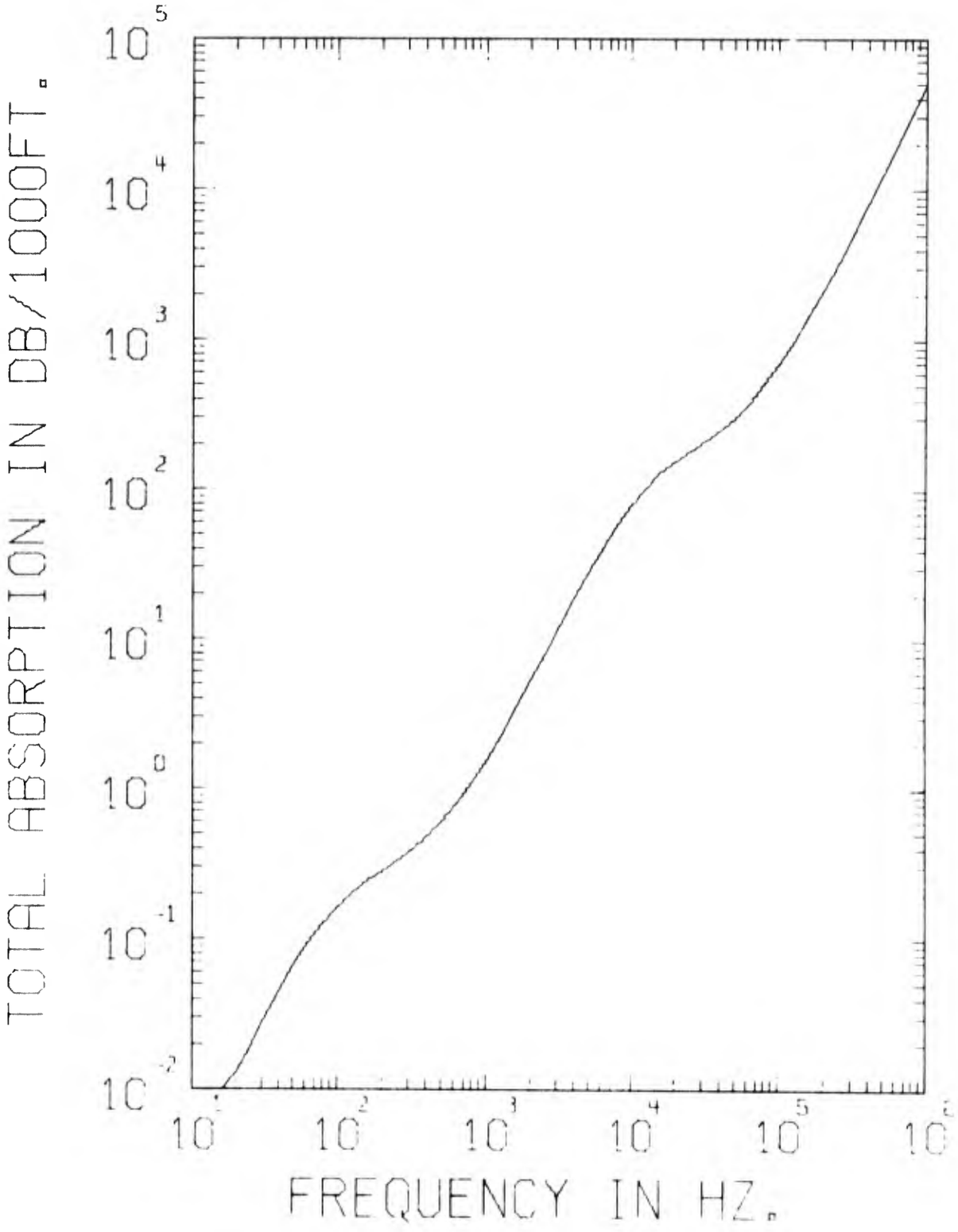


ABSORPTION AND VELOCITY OF SOUND IN STILL AIR

RELATIVE HUMIDITY = 15.0% TEMPERATURE = 68. DEGREES F

FREQUENCY (HZ)	ABSORPTION (DB/1000FT)	ABSORPTION (DB/KM)	ABSORPTION (DB/SEC)	VELOCITY (1000FT/SEC)
12.	0.006	0.02	0.007	1.127363
16.	0.010	0.03	0.012	1.127365
20.	0.016	0.05	0.018	1.127366
25.	0.024	0.08	0.027	1.127369
31.	0.035	0.12	0.040	1.127373
40.	0.054	0.18	0.061	1.127378
50.	0.075	0.25	0.085	1.127383
63.	0.102	0.33	0.115	1.127391
80.	0.133	0.44	0.150	1.127399
100.	0.164	0.54	0.185	1.127407
125.	0.196	0.64	0.221	1.127415
160.	0.234	0.77	0.264	1.127419
200.	0.274	0.90	0.309	1.127424
250.	0.327	1.07	0.369	1.127426
315.	0.404	1.33	0.456	1.127429
400.	0.526	1.72	0.593	1.127431
500.	0.701	2.30	0.791	1.127432
630.	0.985	3.23	1.110	1.127434
800.	1.449	4.75	1.634	1.127435
1000.	2.130	6.99	2.401	1.127437
1250.	3.178	10.42	3.583	1.127440
1600.	4.995	16.38	5.631	1.127445
2000.	7.527	24.69	8.486	1.127453
2500.	11.282	37.00	12.720	1.127463
3150.	16.938	55.56	19.098	1.127479
4000.	25.203	82.67	28.417	1.127502
5000.	35.459	116.31	39.981	1.127530
6300.	48.566	159.30	54.761	1.127567
8000.	64.055	210.10	72.229	1.127608
10000.	79.270	260.00	89.388	1.127646
12500.	94.330	309.40	106.374	1.127681
16000.	110.563	362.65	124.684	1.127713
20000.	125.630	412.07	141.678	1.127736
25000.	142.832	468.49	161.079	1.127752
31500.	165.862	544.03	187.052	1.127763
40000.	200.106	656.35	225.674	1.127771
50000.	248.373	814.66	280.109	1.127777
63000.	325.359	1067.18	366.933	1.127780
80000.	451.116	1479.66	508.760	1.127783
100000.	635.635	2084.88	716.860	1.127786
125000.	921.472	3022.43	1039.224	1.127788
160000.	1423.453	4668.92	1605.355	1.127789
200000.	2141.094	7022.79	2414.707	1.127791
250000.	3252.975	10669.75	3668.686	1.127794
315000.	5055.508	16582.06	5701.582	1.127796
400000.	8024.301	26319.70	9049.789	1.127798
500000.	12408.687	40700.49	13994.504	1.127799
630000.	19554.691	64139.38	22053.797	1.127801
800000.	31371.871	102899.69	35381.254	1.127802
1000000.	48865.840	160279.94	55110.984	1.127802

SOUND ABSORPTION IN STILL AIR FOR 20% RELATIVE HUMIDITY.

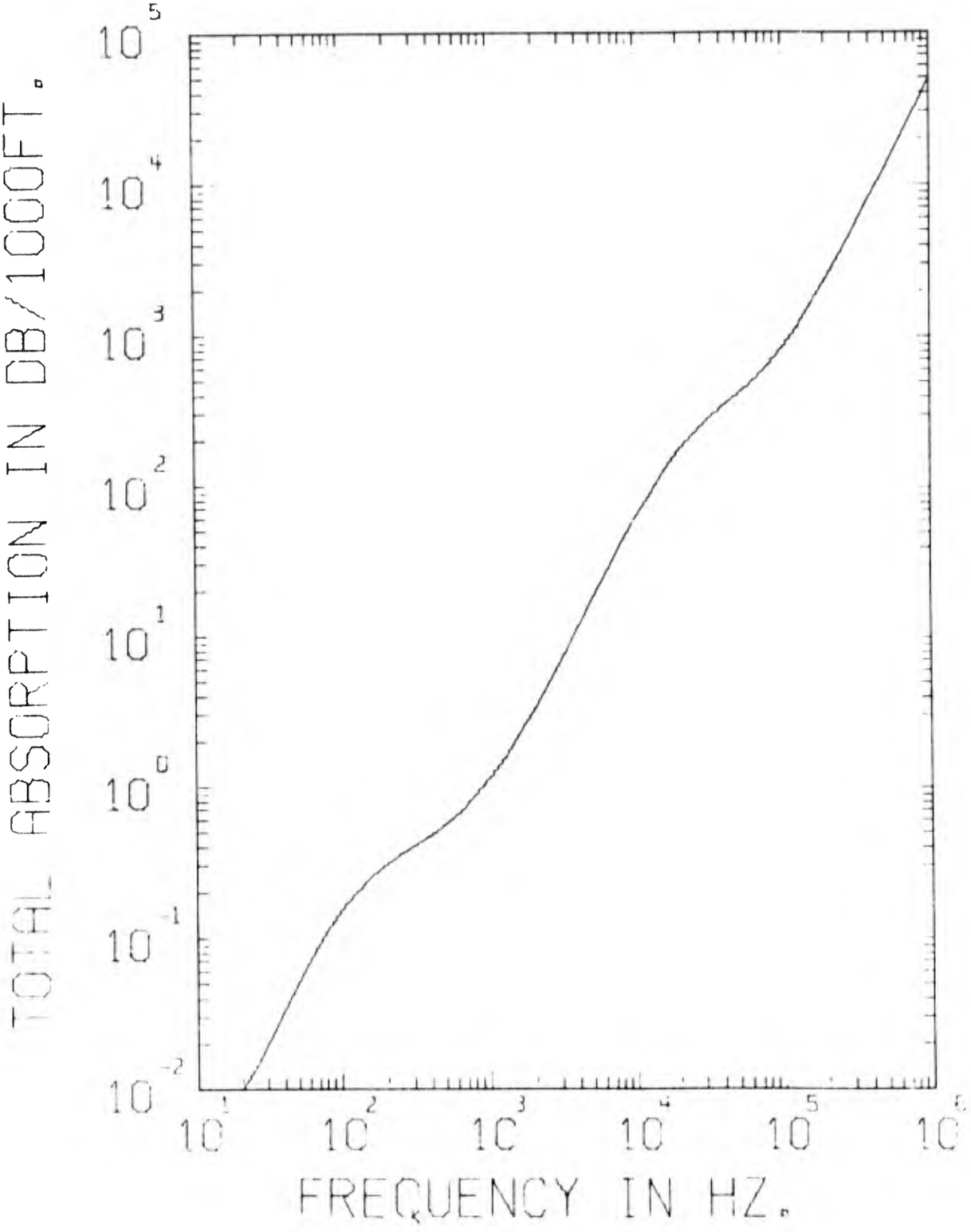


ABSORPTION AND VELOCITY OF SOUND IN STILL AIR

RELATIVE HUMIDITY = 20.0% TEMPERATURE = 68. DEGREES F

FREQUENCY (HZ)	ABSORPTION (DB/1000FT)	ABSORPTION (DB/KM)	ABSORPTION (DB/SEC)	VELOCITY (1000FT/SEC)
12.	0.005	0.02	0.005	1.127567
16.	0.008	0.03	0.009	1.127567
20.	0.013	0.04	0.014	1.127568
25.	0.019	0.06	0.022	1.127570
31.	0.029	0.10	0.033	1.127573
40.	0.045	0.15	0.051	1.127577
50.	0.066	0.22	0.074	1.127582
63.	0.093	0.30	0.105	1.127587
80.	0.127	0.42	0.144	1.127595
100.	0.164	0.54	0.185	1.127603
125.	0.202	0.66	0.228	1.127610
160.	0.245	0.80	0.276	1.127618
200.	0.295	0.93	0.321	1.127624
250.	0.330	1.08	0.373	1.127627
315.	0.390	1.28	0.440	1.127631
400.	0.476	1.56	0.537	1.127633
500.	0.597	1.96	0.674	1.127634
630.	0.789	2.59	0.890	1.127636
800.	1.103	3.62	1.244	1.127637
1000.	1.563	5.13	1.763	1.127639
1250.	2.277	7.47	2.568	1.127640
1600.	3.529	11.58	3.980	1.127643
2000.	5.310	17.42	5.987	1.127645
2500.	8.028	26.33	9.053	1.127650
3150.	12.307	40.37	13.878	1.127659
4000.	18.991	62.29	21.416	1.127670
5000.	28.077	92.09	31.663	1.127687
6300.	41.151	134.98	46.406	1.127710
8000.	59.072	193.76	66.618	1.127742
10000.	79.657	261.28	89.836	1.127778
12500.	103.004	337.85	116.170	1.127817
16000.	130.465	427.93	147.146	1.127859
20000.	155.809	511.05	175.736	1.127893
25000.	182.040	597.09	205.326	1.127921
31500.	212.396	696.66	239.571	1.127944
40000.	251.952	826.40	284.192	1.127960
50000.	303.349	994.98	342.168	1.127970
63000.	382.062	1253.16	430.957	1.127977
80000.	508.369	1667.45	573.431	1.127982
100000.	692.667	2271.95	781.318	1.127986
125000.	978.118	3208.23	1103.306	1.127989
160000.	1480.462	4855.91	1669.948	1.127992
200000.	2200.245	7216.80	2481.864	1.127995
250000.	3316.807	10879.12	3741.346	1.127996
315000.	5126.883	16816.17	5783.113	1.127998
400000.	8105.262	26585.25	9142.742	1.128001
500000.	12498.750	40995.89	14098.629	1.128003
630000.	19653.129	64462.25	22168.809	1.128004
800000.	31477.141	103245.00	35506.371	1.128005
1000000.	48975.668	160640.12	55244.844	1.128006

SOUND ABSORPTION IN STILL AIR FOR 30% RELATIVE HUMIDITY.

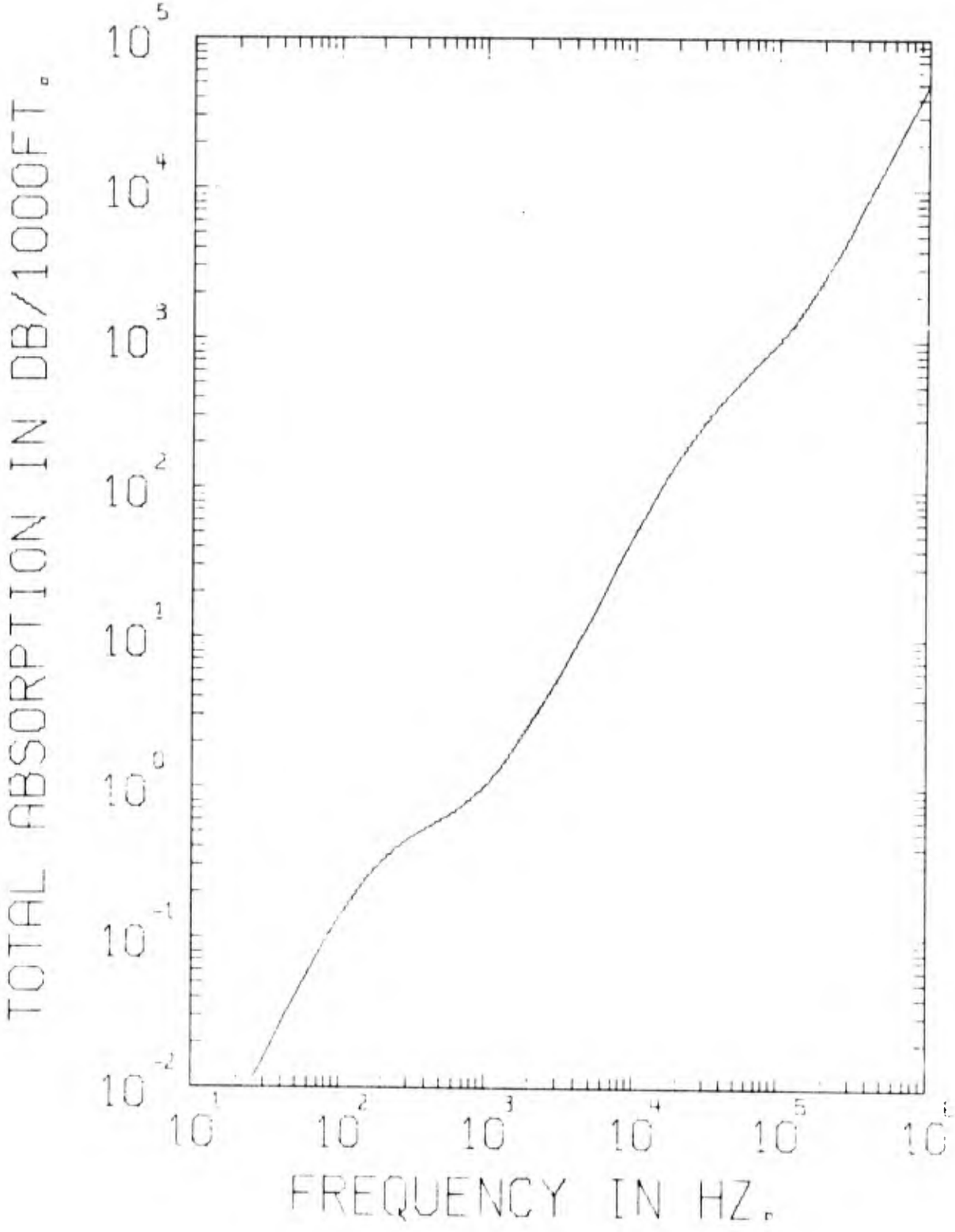


ABSORPTION AND VELOCITY OF SOUND IN STILL AIR

RELATIVE HUMIDITY = 30.0% TEMPERATURE = 68. DEGREES F

FREQUENCY (HZ)	ABSORPTION (DB/1000FT)	ABSORPTION (DB/KM)	ABSORPTION (DB/SEC)	VELOCITY (1000FT/SEC)
12.	0.003	0.01	0.004	1.127975
16.	0.006	0.02	0.007	1.127976
20.	0.009	0.03	0.010	1.127976
25.	0.014	0.05	0.016	1.127977
31.	0.021	0.07	0.024	1.127978
40.	0.034	0.11	0.039	1.127980
50.	0.051	0.17	0.057	1.127984
63.	0.075	0.25	0.085	1.127987
80.	0.110	0.36	0.124	1.127994
100.	0.151	0.50	0.170	1.127999
125.	0.199	0.65	0.224	1.128007
160.	0.256	0.84	0.289	1.128016
200.	0.309	1.01	0.349	1.128023
250.	0.361	1.19	0.408	1.128029
315.	0.417	1.37	0.471	1.128034
400.	0.484	1.59	0.546	1.128037
500.	0.564	1.85	0.637	1.128040
630.	0.682	2.24	0.770	1.128041
800.	0.868	2.85	0.979	1.128044
1000.	1.137	3.73	1.282	1.128045
1250.	1.552	5.09	1.751	1.128045
1600.	2.283	7.49	2.576	1.128046
2000.	3.333	10.93	3.760	1.128047
2500.	4.960	16.27	5.596	1.128049
3150.	7.587	24.89	8.559	1.128053
4000.	11.856	38.89	13.374	1.128056
5000.	18.005	59.06	20.311	1.128062
6300.	27.626	90.61	31.164	1.128072
8000.	42.514	139.44	47.959	1.128086
10000.	62.493	204.98	70.498	1.128105
12500.	89.659	294.08	101.148	1.128131
16000.	128.814	422.51	145.324	1.128166
20000.	171.847	563.66	193.879	1.128204
25000.	220.587	723.53	248.876	1.128243
31500.	275.744	904.44	311.117	1.128283
40000.	338.710	1110.97	382.172	1.128316
50000.	407.767	1337.47	460.100	1.128342
63000.	499.838	1639.47	563.998	1.128361
80000.	635.085	2083.08	716.614	1.128375
100000.	824.065	2702.93	929.861	1.128384
125000.	1111.579	3645.98	1254.295	1.128390
160000.	1614.490	5295.52	1821.781	1.128394
200000.	2334.884	7658.42	2634.680	1.128399
250000.	3454.203	11329.79	3897.725	1.128401
315000.	5271.504	17290.53	5948.387	1.128405
400000.	8263.152	27103.14	9324.191	1.128407
500000.	12673.461	41560.95	14300.852	1.128409
630000.	19847.242	65098.95	22395.871	1.128412
800000.	31690.441	103944.62	35759.910	1.128413
1000000.	49204.289	161390.00	55522.859	1.128415

SOUND ABSORPTION IN STILL AIR FOR 40% RELATIVE HUMIDITY.

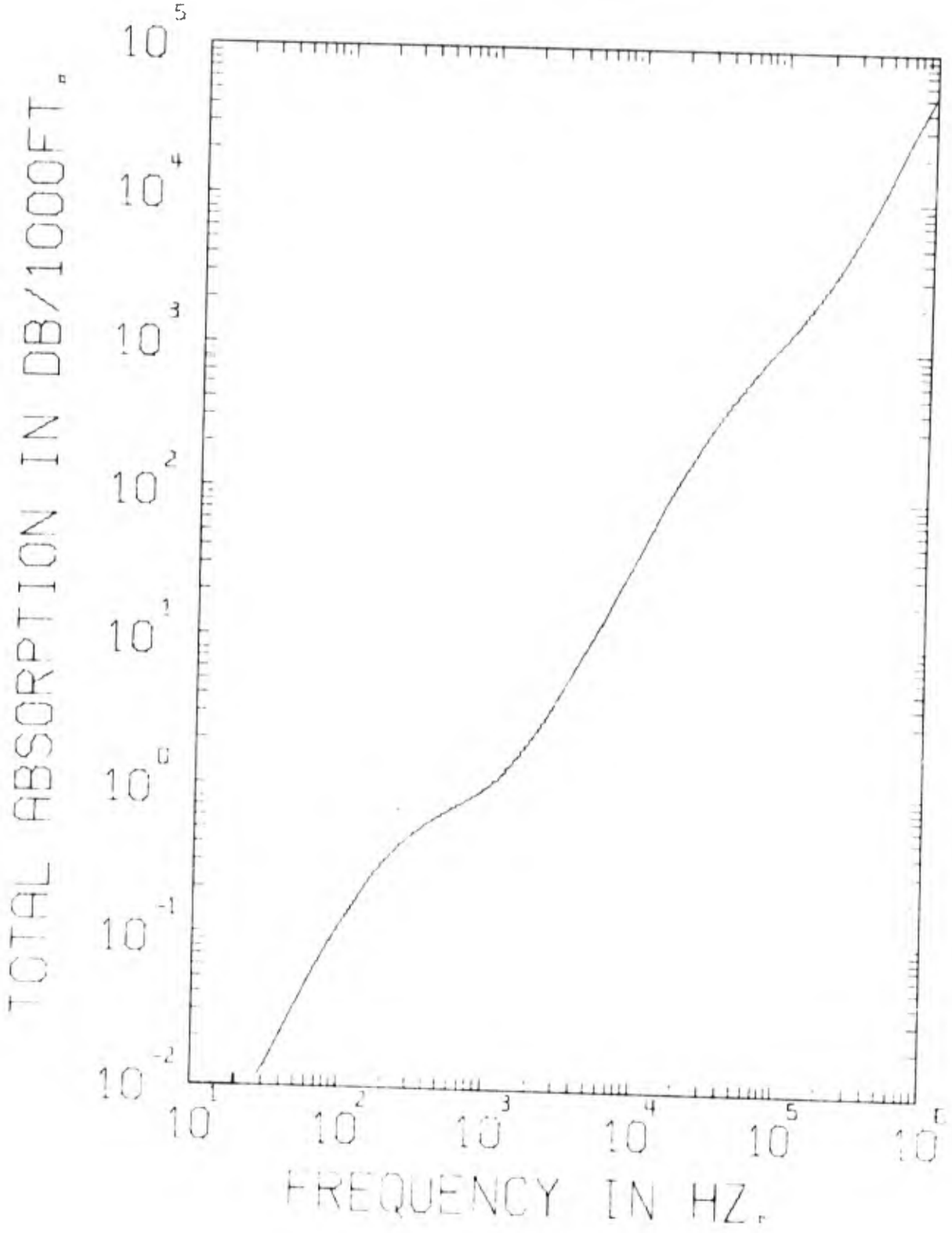


ABSORPTION AND VELOCITY OF SOUND IN STILL AIR

RELATIVE HUMIDITY = 40.0% TEMPERATURE = 68. DEGREES F

FREQUENCY (HZ)	ABSORPTION (DB/1000FT)	ABSORPTION (DB/KM)	ABSORPTION (DB/SEC)	VELOCITY (1000FT/SEC)
12.	0.003	0.01	0.003	1.128385
16.	0.004	0.01	0.005	1.128385
20.	0.007	0.02	0.008	1.128386
25.	0.011	0.04	0.012	1.128386
31.	0.016	0.05	0.018	1.128386
40.	0.027	0.09	0.030	1.128388
50.	0.041	0.13	0.046	1.128390
63.	0.062	0.20	0.070	1.128392
80.	0.093	0.31	0.105	1.128397
100.	0.134	0.44	0.151	1.128402
125.	0.185	0.61	0.208	1.128408
160.	0.252	0.83	0.284	1.128416
200.	0.316	1.04	0.359	1.128424
250.	0.385	1.26	0.434	1.128431
315.	0.453	1.49	0.511	1.128437
400.	0.524	1.72	0.592	1.128443
500.	0.597	1.96	0.674	1.128448
630.	0.692	2.27	0.781	1.128449
800.	0.829	2.72	0.935	1.128451
1000.	1.019	3.34	1.150	1.128452
1250.	1.309	4.29	1.477	1.128453
1600.	1.816	5.96	2.050	1.128455
2000.	2.544	8.34	2.870	1.128456
2500.	3.674	12.05	4.146	1.128456
3150.	5.510	18.07	6.218	1.128458
4000.	8.523	27.96	9.618	1.128460
5000.	12.932	42.42	14.593	1.128462
6300.	19.995	65.58	22.564	1.128467
8000.	31.337	102.79	35.363	1.128474
10000.	47.390	155.44	53.478	1.128484
12500.	70.857	232.41	79.962	1.128499
16000.	108.308	355.25	122.228	1.128521
20000.	154.838	507.87	174.742	1.128549
25000.	214.514	703.61	242.097	1.128583
31500.	289.709	950.25	326.972	1.128622
40000.	380.371	1247.62	429.310	1.128663
50000.	477.377	1565.80	538.815	1.128700
63000.	596.091	1955.18	672.827	1.128733
80000.	753.514	2471.53	850.536	1.128758
100000.	957.505	3140.62	1080.808	1.128776
125000.	1254.962	4116.27	1416.584	1.128787
160000.	1764.122	5786.32	1991.335	1.128797
200000.	2487.192	8157.99	2807.548	1.128802
250000.	3607.926	11833.99	4072.648	1.128806
315000.	5427.473	17802.11	6126.590	1.128811
400000.	8424.953	27633.84	9510.199	1.128814
500000.	12845.848	42134.37	14500.605	1.128817
630000.	20035.941	65717.87	22616.957	1.128819
800000.	31890.719	104631.06	36009.082	1.128821
1000000.	49433.414	162141.56	55801.633	1.128824

SOUND ABSORPTION IN STILL AIR FOR 50% RELATIVE HUMIDITY.

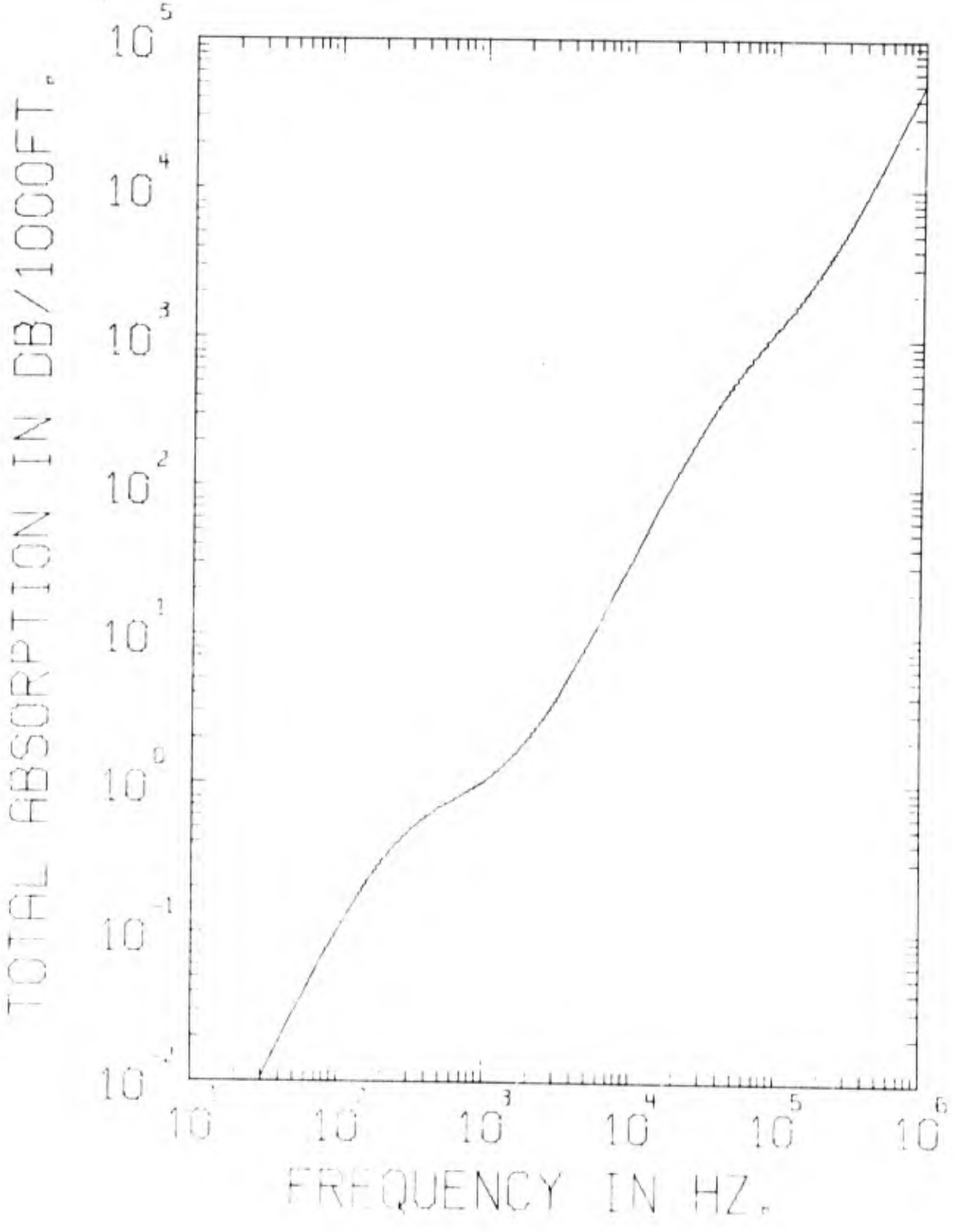


ABSORPTION AND VELOCITY OF SOUND IN STILL AIR

RELATIVE HUMIDITY = 50.0% TEMPERATURE = 68. DEGREES F

FREQUENCY (HZ)	ABSORPTION (DB/1000FT)	ABSORPTION (DB/KM)	ABSORPTION (DB/SEC)	VELOCITY (1000FT/SEC)
12.	0.002	0.01	0.002	1.128795
16.	0.004	0.01	0.004	1.128795
20.	0.006	0.02	0.006	1.128795
25.	0.009	0.03	0.010	1.128796
31.	0.013	0.04	0.015	1.128796
40.	0.022	0.07	0.025	1.128797
50.	0.034	0.11	0.038	1.128798
63.	0.052	0.17	0.058	1.128800
80.	0.080	0.26	0.090	1.128802
100.	0.117	0.38	0.132	1.128807
125.	0.167	0.55	0.189	1.128812
160.	0.238	0.78	0.269	1.128819
200.	0.313	1.03	0.353	1.128826
250.	0.394	1.29	0.445	1.128835
315.	0.478	1.57	0.540	1.128842
400.	0.563	1.85	0.636	1.128849
500.	0.643	2.11	0.726	1.128853
630.	0.734	2.41	0.828	1.128858
800.	0.851	2.79	0.961	1.128860
1000.	1.005	3.30	1.134	1.128861
1250.	1.231	4.04	1.390	1.128862
1600.	1.621	5.32	1.830	1.128863
2000.	2.176	7.14	2.457	1.128865
2500.	3.040	9.97	3.431	1.128865
3150.	4.442	14.57	5.015	1.128866
4000.	6.752	22.15	7.622	1.128867
5000.	10.151	33.29	11.459	1.128868
6300.	15.643	51.31	17.659	1.128871
8000.	24.590	80.65	27.758	1.128875
10000.	37.521	123.07	42.357	1.128881
12500.	57.009	186.99	64.357	1.128890
16000.	89.594	293.87	101.143	1.128903
20000.	132.719	435.32	149.830	1.128922
25000.	192.445	631.22	217.260	1.128946
31500.	274.673	900.93	310.101	1.128980
40000.	382.722	1255.33	432.101	1.129020
50000.	504.796	1655.73	569.944	1.129059
63000.	654.606	2147.11	739.115	1.129099
80000.	844.024	2768.40	953.016	1.129133
100000.	1073.683	3521.68	1212.359	1.129160
125000.	1390.927	4562.24	1570.605	1.129179
160000.	1915.079	6281.46	2162.496	1.129194
200000.	2646.428	8680.28	2988.357	1.129204
250000.	3771.796	12371.49	4259.152	1.129211
315000.	5594.066	18348.54	6316.914	1.129217
400000.	8594.629	28190.38	9705.227	1.129220
500000.	13021.227	42709.62	14703.879	1.129224
630000.	20222.340	66329.25	22835.605	1.129227
800000.	32103.441	105299.25	36252.152	1.129230
1000000.	49657.215	162875.62	56074.535	1.129232

SOUND ABSORPTION IN STILL AIR FOR 60% RELATIVE HUMIDITY.

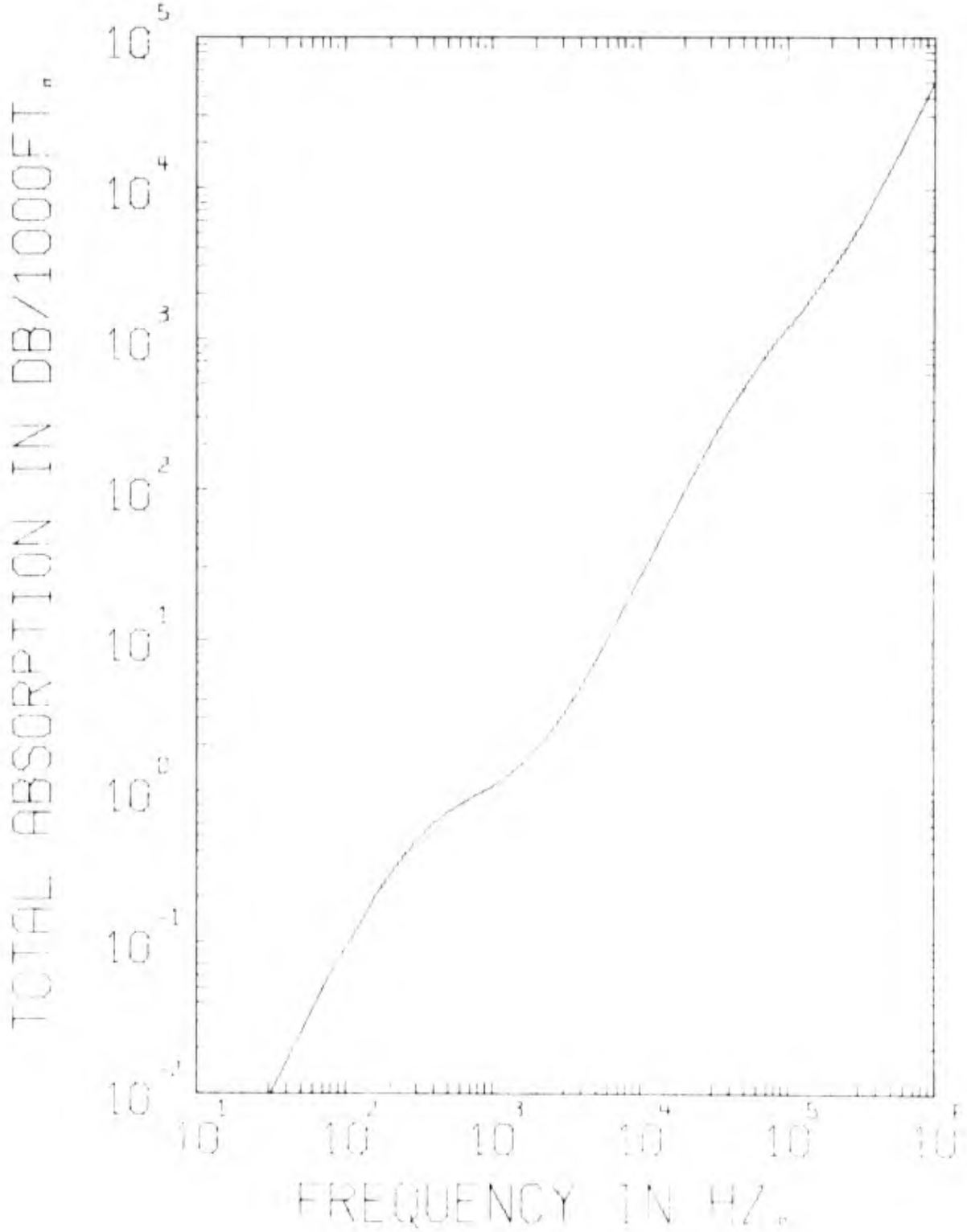


ABSORPTION AND VELOCITY OF SOUND IN STILL AIR

RELATIVE HUMIDITY = 60.0% TEMPERATURE = 68. DEGREES F

FREQUENCY (HZ)	ABSORPTION (DB/1000FT)	ABSORPTION (DB/KM)	ABSORPTION (DB/SEC)	VELOCITY (1000FT/SEC)
12.	0.002	0.01	0.002	1.129207
16.	0.003	0.01	0.003	1.129207
20.	0.005	0.02	0.005	1.129207
25.	0.007	0.02	0.008	1.129207
31.	0.011	0.04	0.013	1.129208
40.	0.018	0.06	0.021	1.129208
50.	0.029	0.09	0.032	1.129209
63.	0.044	0.15	0.050	1.129210
80.	0.069	0.23	0.078	1.129211
100.	0.103	0.34	0.117	1.129215
125.	0.151	0.49	0.170	1.129219
160.	0.221	0.73	0.250	1.129225
200.	0.301	0.99	0.339	1.129232
250.	0.391	1.28	0.442	1.129239
315.	0.491	1.61	0.554	1.129247
400.	0.593	1.94	0.669	1.129254
500.	0.685	2.25	0.774	1.129261
630.	0.782	2.57	0.884	1.129266
800.	0.896	2.94	1.012	1.129269
1000.	1.032	3.39	1.166	1.129271
1250.	1.223	4.01	1.381	1.129273
1600.	1.544	5.07	1.744	1.129274
2000.	1.997	6.55	2.256	1.129275
2500.	2.698	8.85	3.047	1.129275
3150.	3.836	12.58	4.331	1.129276
4000.	5.711	18.73	6.449	1.129277
5000.	8.476	27.80	9.571	1.129278
6300.	12.962	42.51	14.638	1.129279
8000.	20.316	66.64	22.942	1.129282
10000.	31.050	101.84	35.064	1.129286
12500.	47.462	155.67	53.598	1.129292
16000.	75.544	247.78	85.312	1.129300
20000.	113.958	373.78	128.694	1.129313
25000.	169.534	556.07	191.460	1.129331
31500.	250.538	821.76	282.946	1.129355
40000.	364.443	1195.37	411.598	1.129389
50000.	501.573	1645.16	566.489	1.129426
63000.	677.023	2220.64	764.675	1.129467
80000.	899.912	2951.71	1016.458	1.129508
100000.	1161.739	3810.50	1312.232	1.129541
125000.	1507.465	4944.48	1702.784	1.129568
160000.	2056.069	6743.90	2322.516	1.129591
200000.	2802.800	9193.18	3166.055	1.129604
250000.	3938.053	12916.81	4448.484	1.129616
315000.	5766.312	18913.50	6513.758	1.129623
400000.	8770.633	28767.67	9907.551	1.129628
500000.	13201.043	43299.41	14912.320	1.129632
630000.	20409.176	66942.06	23054.934	1.129636
800000.	32303.223	105954.50	36490.969	1.129639
1000000.	49874.566	163598.56	56340.379	1.129642

SOUND ABSORPTION IN STILL AIR FOR 70% RELATIVE HUMIDITY.

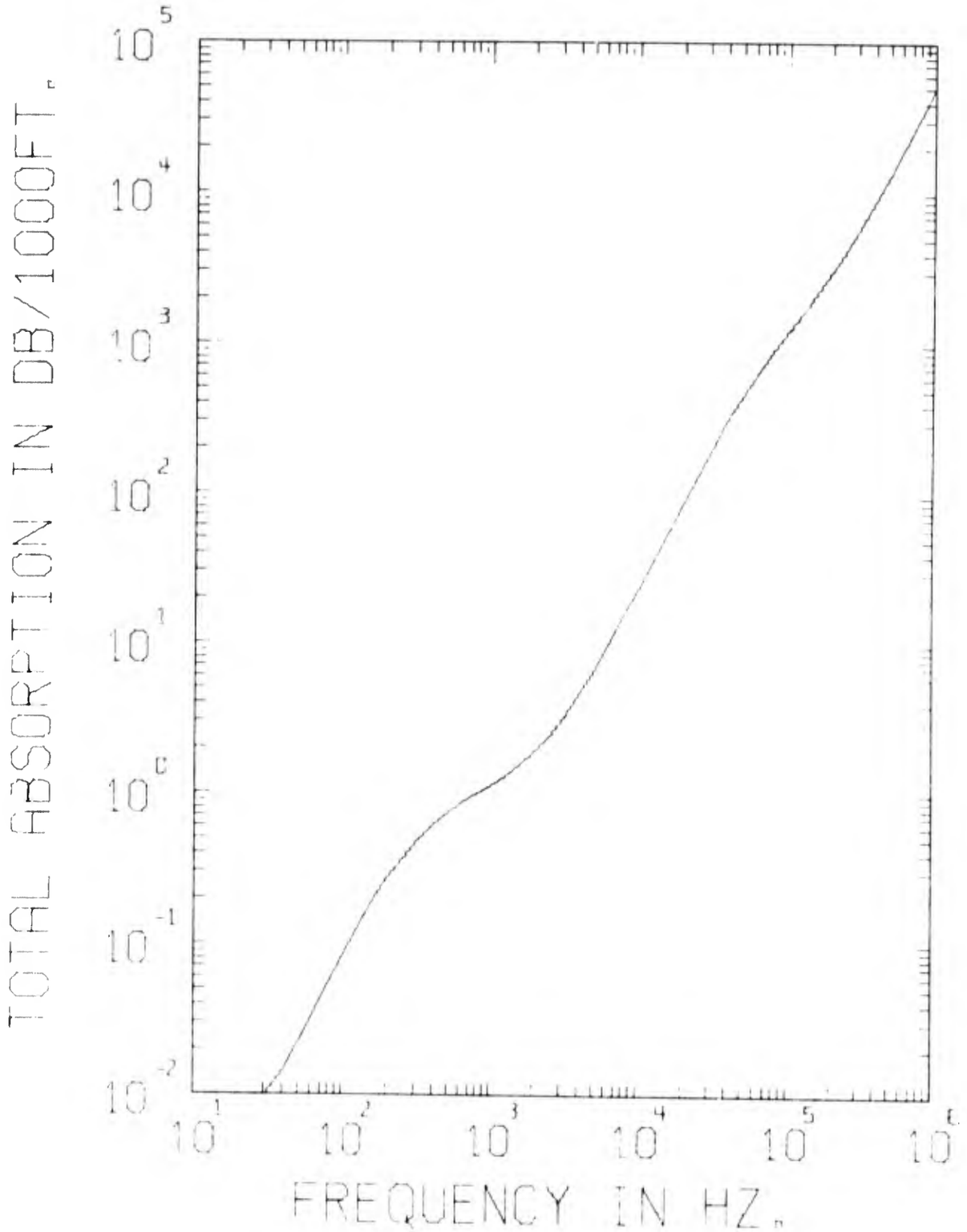


ABSORPTION AND VELOCITY OF SOUND IN STILL AIR

RELATIVE HUMIDITY = 70.0% TEMPERATURE = 68. DEGREES F

FREQUENCY (HZ)	ABSORPTION (DB/1000FT)	ABSORPTION (DB/KM)	ABSORPTION (DB/SEC)	VELOCITY (1000FT/SEC)
12.	0.001	0.00	0.002	1.129618
16.	0.003	0.01	0.003	1.129618
20.	0.004	0.01	0.005	1.129618
25.	0.006	0.02	0.007	1.129618
31.	0.010	0.03	0.011	1.129618
40.	0.016	0.05	0.018	1.129619
50.	0.025	0.08	0.028	1.129619
63.	0.039	0.13	0.044	1.129620
80.	0.061	0.20	0.069	1.129622
100.	0.092	0.30	0.104	1.129623
125.	0.136	0.45	0.153	1.129627
160.	0.204	0.67	0.230	1.129632
200.	0.284	0.93	0.321	1.129638
250.	0.381	1.25	0.431	1.129645
315.	0.493	1.62	0.557	1.129654
400.	0.611	2.01	0.691	1.129662
500.	0.720	2.36	0.813	1.129668
630.	0.829	2.72	0.937	1.129673
800.	0.947	3.11	1.070	1.129678
1000.	1.078	3.53	1.217	1.129681
1250.	1.250	4.10	1.412	1.129683
1600.	1.528	5.01	1.726	1.129684
2000.	1.915	6.28	2.163	1.129685
2500.	2.509	8.23	2.834	1.129686
3150.	3.471	11.38	3.921	1.129686
4000.	5.056	16.58	5.712	1.129687
5000.	7.395	24.26	8.354	1.129687
6300.	11.197	36.73	12.649	1.129689
8000.	17.450	57.24	19.713	1.129690
10000.	26.624	87.33	30.077	1.129693
12500.	40.758	133.69	46.044	1.129697
16000.	65.246	214.01	73.708	1.129704
20000.	99.365	325.92	112.254	1.129712
25000.	150.000	492.00	169.459	1.129725
31500.	226.468	742.82	255.851	1.129744
40000.	339.153	1112.42	383.165	1.129770
50000.	482.023	1581.04	544.591	1.129803
63000.	673.667	2209.63	761.137	1.129842
80000.	924.481	3032.30	1044.556	1.129884
100000.	1218.987	3998.28	1377.358	1.129921
125000.	1598.232	5242.20	1805.929	1.129954
160000.	2179.337	7148.22	2462.616	1.129984
200000.	2948.748	9671.89	3332.094	1.130003
250000.	4100.031	13448.10	4633.105	1.130017
315000.	5938.926	19479.67	6711.148	1.130028
400000.	8949.742	29355.15	10113.516	1.130034
500000.	13384.277	43900.43	15124.770	1.130040
630000.	20597.547	67559.94	23276.133	1.130044
800000.	32500.840	106602.69	36727.531	1.130049
1000000.	50086.289	164283.00	56600.090	1.130052

SOUND ABSORPTION IN STILL AIR FOR 80% RELATIVE HUMIDITY.

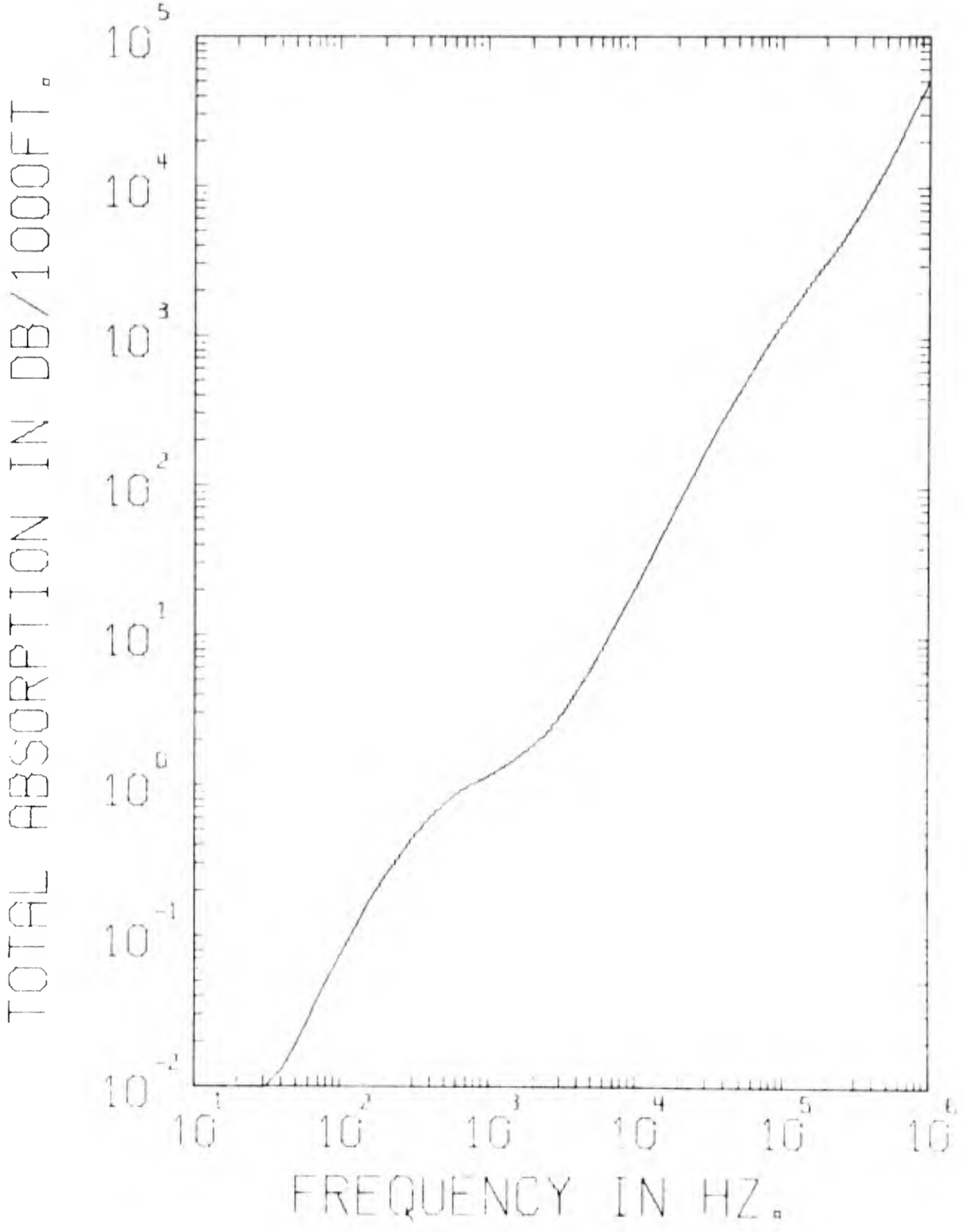


ABSORPTION AND VELOCITY OF SOUND IN STILL AIR

RELATIVE HUMIDITY = 80.0% TEMPERATURE = 68. DEGREES F

FREQUENCY (HZ)	ABSORPTION (DB/1000FT)	ABSORPTION (DB/KM)	ABSORPTION (DB/SEC)	VELOCITY (1000FT/SEC)
12.	0.001	0.00	0.001	1.130030
16.	0.002	0.01	0.003	1.130030
20.	0.004	0.01	0.004	1.130030
25.	0.006	0.02	0.006	1.130030
31.	0.008	0.03	0.010	1.130030
40.	0.014	0.05	0.016	1.130030
50.	0.022	0.07	0.025	1.130031
63.	0.034	0.11	0.039	1.130032
80.	0.054	0.18	0.061	1.130033
100.	0.082	0.27	0.093	1.130034
125.	0.123	0.40	0.139	1.130036
160.	0.188	0.62	0.212	1.130041
200.	0.267	0.88	0.302	1.130047
250.	0.367	1.20	0.414	1.130053
315.	0.487	1.60	0.550	1.130060
400.	0.620	2.03	0.701	1.130069
500.	0.745	2.44	0.842	1.130076
630.	0.870	2.85	0.983	1.130082
800.	0.998	3.27	1.128	1.130088
1000.	1.130	3.71	1.277	1.130091
1250.	1.293	4.24	1.461	1.130094
1600.	1.545	5.07	1.746	1.130095
2000.	1.887	6.19	2.132	1.130096
2500.	2.407	7.90	2.720	1.130097
3150.	3.246	10.65	3.668	1.130098
4000.	4.626	15.17	5.228	1.130098
5000.	6.663	21.85	7.529	1.130099
6300.	9.976	32.72	11.274	1.130100
8000.	15.435	50.63	17.443	1.130101
10000.	23.466	76.97	26.519	1.130102
12500.	35.896	117.74	40.566	1.130106
16000.	57.588	188.89	65.081	1.130110
20000.	88.144	289.11	99.612	1.130116
25000.	134.198	440.17	151.660	1.130126
31500.	205.333	673.49	232.055	1.130140
40000.	313.525	1028.36	354.334	1.130161
50000.	456.068	1495.90	515.443	1.130189
63000.	655.232	2149.33	740.615	1.130223
80000.	925.566	3035.86	1046.134	1.130264
100000.	1248.492	4095.05	1411.174	1.130303
125000.	1661.857	5450.89	1878.465	1.130341
160000.	2280.556	7480.22	2577.883	1.130375
200000.	3078.994	10099.10	3480.494	1.130400
250000.	4252.531	13948.30	4807.137	1.130418
315000.	6107.367	20032.16	6903.961	1.130432
400000.	9128.473	29941.39	10319.203	1.130442
500000.	13568.906	44506.01	15338.945	1.130448
630000.	20787.070	68181.56	23498.805	1.130453
800000.	32697.352	107247.25	36962.945	1.130457
1000000.	50293.703	164963.31	56855.102	1.130462

SOUND ABSORPTION IN STILL AIR FOR 90% RELATIVE HUMIDITY.

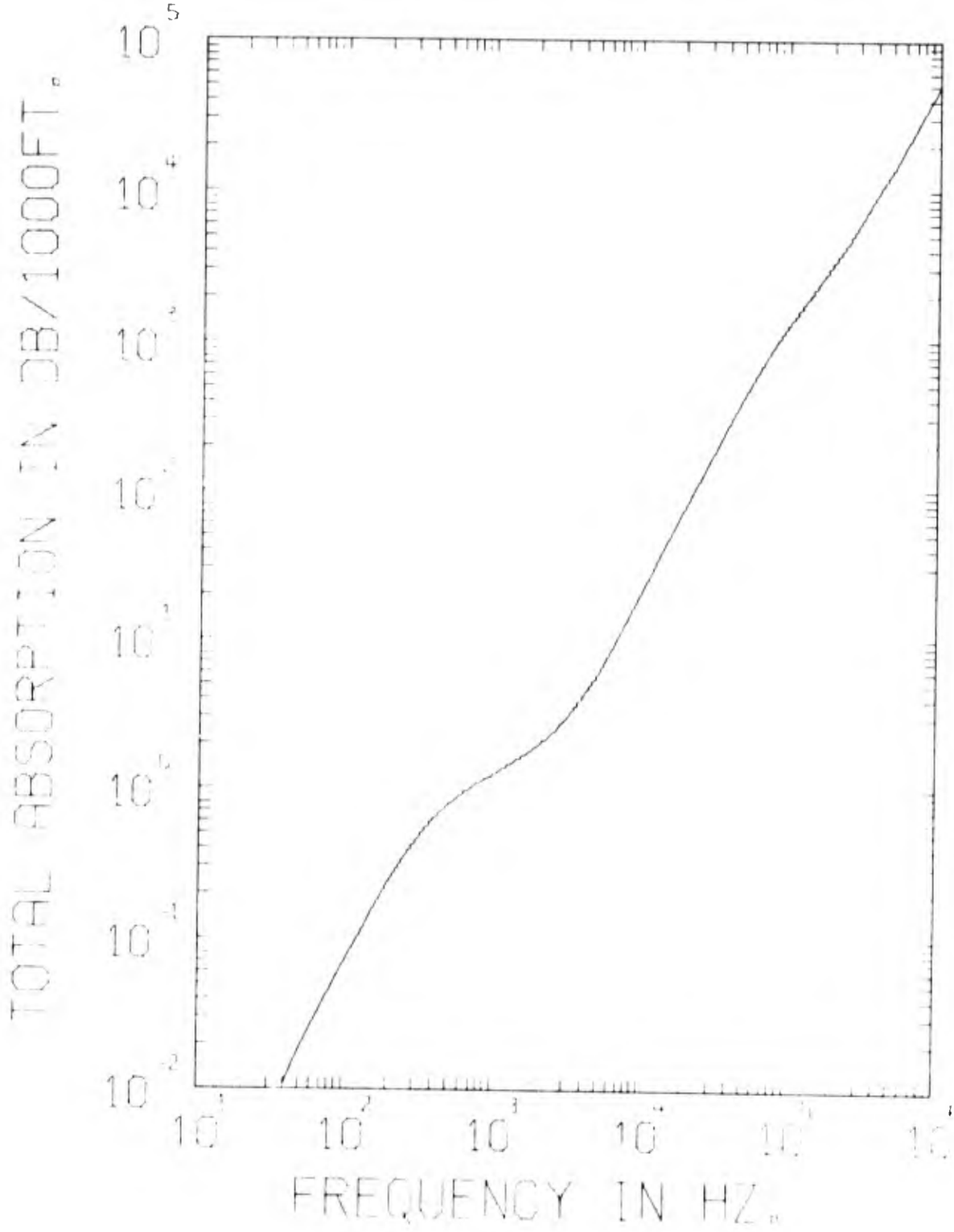


ABSORPTION AND VELOCITY OF SOUND IN STILL AIR

RELATIVE HUMIDITY = 90.0% TEMPERATURE = 68. DEGREES F

FREQUENCY (HZ)	ABSORPTION (DB/1000FT)	ABSORPTION (DB/KM)	ABSORPTION (DB/SEC)	VELOCITY (1000FT/SEC)
12.	0.001	0.00	0.001	1.130443
16.	0.002	0.01	0.002	1.130443
20.	0.003	0.01	0.004	1.130443
25.	0.005	0.02	0.006	1.130443
31.	0.008	0.02	0.009	1.130443
40.	0.013	0.04	0.014	1.130443
50.	0.019	0.06	0.022	1.130444
63.	0.031	0.10	0.035	1.130444
80.	0.049	0.16	0.055	1.130445
100.	0.074	0.24	0.084	1.130446
125.	0.112	0.37	0.127	1.130448
160.	0.173	0.57	0.196	1.130452
200.	0.250	0.82	0.283	1.130457
250.	0.350	1.15	0.396	1.130463
315.	0.476	1.56	0.538	1.130470
400.	0.621	2.04	0.702	1.130478
500.	0.761	2.50	0.860	1.130486
630.	0.903	2.96	1.021	1.130493
800.	1.045	3.43	1.182	1.130498
1000.	1.184	3.88	1.338	1.130503
1250.	1.344	4.41	1.520	1.130505
1600.	1.581	5.18	1.787	1.130507
2000.	1.892	6.21	2.139	1.130508
2500.	2.359	7.74	2.667	1.130510
3150.	3.108	10.19	3.513	1.130510
4000.	4.337	14.22	4.903	1.130511
5000.	6.149	20.17	6.952	1.130511
6300.	9.099	29.84	10.286	1.130512
8000.	13.963	45.80	15.785	1.130513
10000.	21.133	69.32	23.891	1.130514
12500.	32.258	105.81	36.468	1.130516
16000.	51.762	169.78	58.518	1.130520
20000.	79.424	260.51	89.791	1.130526
25000.	121.533	398.63	137.397	1.130531
31500.	187.539	615.13	212.021	1.130544
40000.	290.117	951.58	327.995	1.130561
50000.	429.066	1407.34	485.094	1.130582
63000.	629.701	2065.42	711.948	1.130612
80000.	911.286	2989.02	1030.346	1.130651
100000.	1256.028	4119.77	1420.177	1.130690
125000.	1700.482	5577.58	1922.783	1.130729
160000.	2358.361	7735.42	2666.759	1.130768
200000.	3190.381	10464.45	3607.671	1.130796
250000.	4391.773	14405.02	4966.301	1.130819
315000.	6267.992	20559.01	7088.074	1.130836
400000.	9303.785	30516.41	10521.172	1.130849
500000.	13752.715	45108.90	15552.359	1.130857
630000.	20976.715	68803.56	23721.773	1.130862
800000.	32892.934	107888.81	37197.562	1.130868
1000000.	50497.855	165632.94	57106.598	1.130872

SOUND ABSORPTION IN STILL AIR FOR 100% RELATIVE HUMIDITY.

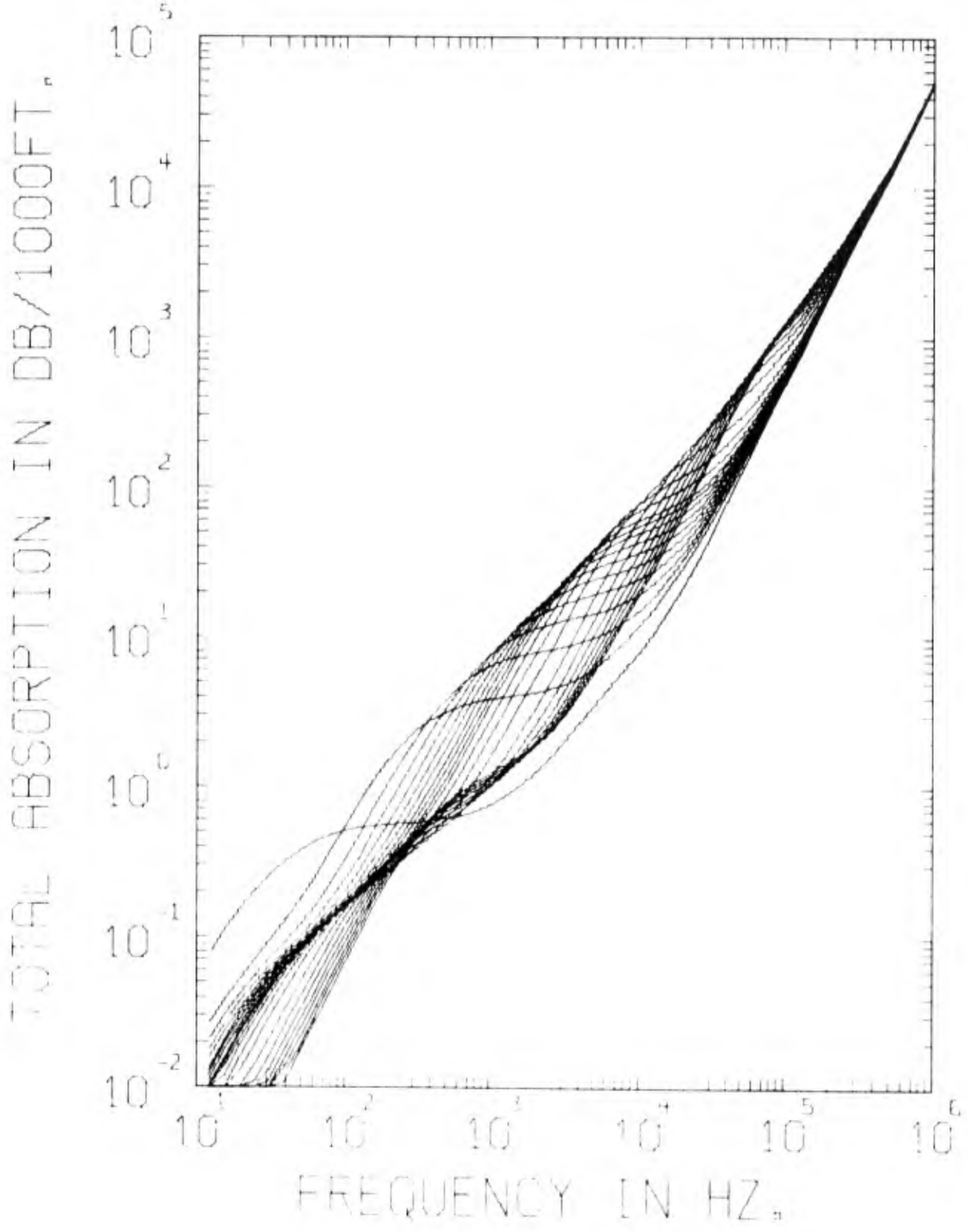


ABSORPTION AND VELOCITY OF SOUND IN STILL AIR

RELATIVE HUMIDITY = 100.0% TEMPERATURE = 68. DEGREES F

FREQUENCY (HZ)	ABSORPTION (DB/1000FT)	ABSORPTION (DB/KM)	ABSORPTION (DB/SEC)	VELOCITY (1000FT/SEC)
12.	0.001	0.00	0.001	1.130856
16.	0.002	0.01	0.002	1.130856
20.	0.003	0.01	0.003	1.130856
25.	0.004	0.01	0.005	1.130856
31.	0.007	0.02	0.008	1.130856
40.	0.011	0.04	0.013	1.130856
50.	0.018	0.06	0.020	1.130857
63.	0.028	0.09	0.031	1.130857
80.	0.044	0.14	0.050	1.130857
100.	0.068	0.22	0.076	1.130858
125.	0.103	0.34	0.116	1.130860
160.	0.160	0.53	0.181	1.130864
200.	0.234	0.77	0.265	1.130868
250.	0.333	1.09	0.377	1.130873
315.	0.461	1.51	0.522	1.130880
400.	0.616	2.02	0.696	1.130888
500.	0.769	2.52	0.870	1.130896
630.	0.928	3.05	1.050	1.130902
800.	1.087	3.57	1.230	1.130909
1000.	1.236	4.05	1.397	1.130914
1250.	1.399	4.59	1.582	1.130917
1600.	1.627	5.34	1.840	1.130920
2000.	1.917	6.29	2.168	1.130921
2500.	2.346	7.69	2.653	1.130922
3150.	3.027	9.93	3.423	1.130923
4000.	4.140	13.58	4.682	1.130924
5000.	5.781	18.96	6.538	1.130924
6300.	8.451	27.72	9.557	1.130925
8000.	12.856	42.17	14.540	1.130925
10000.	19.357	63.49	21.891	1.130926
12500.	29.461	96.63	33.318	1.130929
16000.	47.227	154.90	53.410	1.130931
20000.	72.538	237.93	82.036	1.130935
25000.	111.323	365.14	125.899	1.130940
31500.	172.729	566.55	195.348	1.130949
40000.	269.598	884.28	304.905	1.130963
50000.	403.475	1323.40	456.322	1.130981
63000.	601.714	1973.62	680.543	1.131007
80000.	888.113	2913.01	1004.492	1.131042
100000.	1247.764	4092.67	1411.319	1.131079
125000.	1718.102	5635.37	1943.378	1.131119
160000.	2413.618	7916.66	2730.190	1.131161
200000.	3281.588	10763.61	3712.110	1.131193
250000.	4515.281	14810.12	5107.773	1.131220
315000.	6417.992	21051.01	7260.285	1.131240
400000.	9473.066	31071.65	10716.453	1.131255
500000.	13933.668	45702.43	15762.664	1.131265
630000.	21165.273	69422.06	23943.687	1.131272
800000.	33087.422	108526.60	37431.102	1.131279
1000000.	50699.195	166293.31	57355.176	1.131284

SOUND ABSORPTION IN STILL AIR



APPENDIX

PREPRINT OF

ATMOSPHERIC ABSORPTION OF SOUND: ANALYTICAL EXPRESSIONS

by

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480

ATMOSPHERIC ABSORPTION OF SOUND: ANALYTICAL EXPRESSIONS

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Huntsville, Alabama 35807

ABSTRACT

A set of analytical expression has been developed which will predict the absorption of sound in air at 20° C. The results agree within 3% of previous work in the frequency range of 100 Hz - 1 MHz for all humidities. Below 100 Hz accuracy cannot be judged because of lack of knowledge about the vibration-vibration energy transfer between CO_2 and O_2.

I. LIST OF SYMBOLS

A_i = β_i/β^{∞} = relaxation strength

a_d = $\left[\left(M_{O_2} - M_{N_2}\right)\Big/\left(X_{O_2} M_{O_2} + X_{N_2} M_{N_2}\right)\right]^2 X_{O_2} X_{N_2}$ =
Molecular diffusion constant

C_p = Specific heat at constant pressure

C_v = Specific heat at constant volume

C_p^{dyn}, C_v^{dyn} = Frequency dependent complex specific heats

C_p^{∞}, C_v^{∞} = High frequency limits of specific heats (value of the specific heats at frequencies above the vibrational relaxation effects)

C' = Total vibrational specific heat = $\sum C_i'$

C_i' = Vibrational specific heat of the i-th vibrational mode

c = Velocity of sound in 1000 ft/sec

D_{12} = Diffusion coefficient for O_2 and N_2 mixture

f = Sound frequency

H = Percent relative humidity

h = Mole fraction of water vapor

j = $\sqrt{-1}$

k = Wave number

M = Molecular mass

P = Ambient pressure

P_w = Vapor pressure of water

R = Universal gas constant

S = Entropy

T_i = $2\pi \tau_i^{ps}$ = modified relaxation time

V	=	Frequency dependent sound velocity
V_o	=	Low frequency limit of sound velocity
V_∞	=	High frequency limit of sound velocity
X_i	=	Concentration of molecular species ($i = O_2$, N_2, etc)
α	=	Total amplitude sound absorption coefficient
α_{cl}	=	Amplitude sound absorption coefficient due to classical effects
α_{rot}	=	Amplitude sound absorption coefficient due to rotation
α_{vib}	=	Amplitude sound absorption coefficient due to vibration
$\alpha_{relaxation}$	=	$\alpha_{rot} + \alpha_{vib}$
β	=	$(\beta^o - \beta^\infty) = \Sigma\beta_i$ = total adiabatic compressibility of vibrational modes
β^o	=	Low frequency limit of the adiabatic compressibility
β^∞	=	High frequency limit of the adiabatic compressibility
β_i	=	Adiabatic compressibility of the i-th vibrational process
γ	=	C_p/C_v
η	=	Coefficient of shear viscosity
θ	=	Absolute temperature
κ	=	Coefficient of heat conductivity
ρ	=	Density
τ_i^{pt}	=	Isobaric-isothermal relaxation time of the i-th vibrational process
τ_i^{ps}	=	Isobaric-isentropic relaxation time of the i-th vibrational process
ω	=	$2\pi f$

II. INTRODUCTION

In a previous paper[1] a calculation of sound absorption in still air was discussed and results were presented in graphical form over the relative humidity range of 0-100% at 20° C. The calculations were based on fundamental physical principles with as few empirical steps as possible. The method was quite successful and agreement between the predicted values and available experimental data was very good. However, in two oral presentations of those results, desires were expressed for a more usable format than the graphs of absorption in dB/1000 ft as functions of frequency which were presented. To fulfill these needs a set of tables has been produced which cover an expanded frequency range[2], and now in this paper an analytical expression for sound absorption is developed which can be easily programmed for computer computation or solved manually if necessary.

The absorption of sound in air as in all molecular gases is caused by two different mechanisms:

- Classical effects
- Relaxation effects

The classical effects are a result of the transport processes which occur in a gas, i.e., internal friction, heat conduction, and molecular diffusion. Of these mechanisms the internal friction, or viscosity, and heat conduction are the largest contributors to the classical effects. Numerical inspection of the general equation for binary mixtures[3] has shown that the largest of the diffusion terms contributes only 0.5 percent of the total classical absorption, so only that term has been included in the expression for air[1]. For the frequencies of interest, i.e., well below the collision frequency of the molecules, there is no translational dispersion and the transport properties of the gas obey the ordinary equations of continuum hydrodynamics, so

$$\alpha_{cl} = \frac{2\pi^2 f^2}{\gamma P V_0} \left[\frac{4}{3}\eta + \frac{\gamma-1}{C_p}\kappa + \gamma a_d D_{12} \rho \right] \tag{1}$$

and

$$V^2 = \frac{P}{\rho}\frac{C_p}{C_v} = \frac{\gamma R\theta}{M} = \frac{1}{\rho\beta} \tag{2}$$

The relaxation effects are a result of an additional loss mechanism inherent in molecular gases. As a sound wave progresses in a molecular gas part of the compressional energy is stored in the internal degrees of freedom of the molecules. Since this storage involves excitation and de-excitation of internal energy states which occur during collisions, it requires time, and a phase lag between the internal and translational energy modes of the gas results. This relaxation effect can be taken into account by introducing into Eq. (2) either frequency-dependent and complex dynamic heat capacities C_p^{dyn} and C_v^{dyn} or adiabatic compressibility β. If the transport processes are neglected and only one internal storage mode for the energy with a single relaxation time is considered then

$$C_p^{dyn} = C_p^{\infty} + \frac{C'}{1 + j\omega\tau^{pt}} \tag{3}$$

and the well known bell shaped absorption curve for $\alpha\lambda$ versus f would be obtained along with the S-shaped dispersion curve for the speed of sound[4].

In the presence of internal relaxation, the classical absorption is altered in several ways[3]

- the heat capacities appearing in Eq. (1) must be considered as frequency dependent and complex

- the diffusion of excited molecules supplies an additional and frequency dependent mechanism for the heat conduction, so that $\kappa = \kappa(\omega)$.
- for infrared active modes the emission and re-absorption of radiation must be considered along with the diffusion outlined above. (However, it can be shown that there is no influence in the full frequency range in air owing to radiation effects. For high frequencies there is only small coupling into the internal modes due to the inefficient collision processes occuring in air, and for low frequencies the chance that the infrared photons are re-absorbed in essentially the same portion of the acoustic wavelength is very high.)
- if both the transport and relaxation parts of the absorption become very large, then after the above mentioned alterations have been applied the sound absorption is no longer a simple sum of separate absorption processes.

Fortunately, numerical estimates show that all these complicated interdependances become negligible for the special case of air below a frequency of 1 MHz. This means that the dispersion can be calculated as if the transport processes are absent, i.e.,

$$V^2 = \frac{p}{\rho} \operatorname{Re} \frac{C_p^{dyn}}{C_v^{dyn}} \tag{4}$$

Also the absorption can be obtained by simple addition of the transport and relaxation contributions

$$\alpha = \alpha_{classical} + \alpha_{relaxation} \tag{5}$$

where Eq. (1) for the classical absorption can be expressed as[1]

$$\alpha_{cl} = \frac{2\ ^2 f^2}{\gamma P V_0} \quad (1.9) \quad \eta \tag{6}$$

III. THEORETICAL METHOD

The fact that in air there is more than one storage mode for the internal energy must be taken into account. These modes are sub-divided into

- rotational degrees of freedom
- vibrational degrees of freedom

The frequency range important for absorption in air is well below the rotational relaxation frequency and the contributions owing to rotation give a term which is linear in frequency for frequencies less than 1 MHz. There is also negligible velocity dispersion in this region as a result of rotation. To calculate the absorption due to rotation the rate constant for dry air can be taken from Greenspan[5], assuming that it is not humidity dependent. Unfortunately, there is no experimental verification of that assumption. In fact, very little is known about rotational relaxation in a mixture of rotators; however, it is thought that the error introduced by this assumption is small. When these assumptions are made the absorption due to relaxation effects is

$$\alpha_{relaxation} \quad \alpha_{rotation} + \alpha_{vibration} \tag{7}$$

where

$$\alpha_{rot} = \frac{2\pi^2 f^2}{\gamma P V_0} \quad (0.6) \quad \eta$$

at 20° C and the rotational relaxation rate has been taken from Greenspan.

For the vibrational relaxation processes a simple extension of the addition technique applied above would lead to

$$C_{vib}^{dyn} = \sum \frac{C_i'}{1 + j\omega\tau_i^{pt}} \tag{8}$$

as a representation of the vibrational dynamic heat capacity where the C_i' are the vibrational heat capacities of O_2, N_2, CO_2 and H_2O, and the τ_i^{pt} are closely connected to the lifetimes of the corresponding vibrational quantas. However, this interpretation of Eq. (8) is correct only if the vibrational energy is converted totally into translational energy (V-T process). If instead there is a vibration to vibration exchange of energy between the molecules (V-V process), then the heat capacities of these modes are coupled via that process. As a result of this coupling, each C_i' contains part of the heat capacities of all the vibrational degrees of freedom which are present in air and each τ_i^{pt} contains lifetimes of all quanta which depend upon the transition probabilities of all V-T and V-V processes. Furthermore, depending upon the number of excited levels involved, there can even be more than four vibrational relaxation times present in Eq. (8). Since at least three close resonances between vibrational states exist in air, namely those between N_2 and CO_2; O_2 and CO_2; and O_2 and H_2O, these V-V processes certainly must be considered. These processes totally dominate the sound absorption in the audible region, and there are no other means to predict the acoustic behavior except to investigate their influence and to determine their rates.

The method of calculation of the C_i' and τ_i^{pt} proceeds in a standard way. The coupled equations for the V-V processes owing to the excited vibrational levels are decoupled by means of a main axis transformation[6]. Each of the decoupled equations furnishes one term in Eq. (8). The significance of these terms is that they form the simplest mathematical representation of the dynamic heat capacities. Now, the dispersion and absorption can be given by

$$\frac{1}{V^2} = \frac{\rho}{P} \operatorname{Re} \left[\frac{C_v^{\infty} + C_{vib}^{dyn}}{C_p^{\infty} + C_{vib}^{dyn}} \right] \tag{9}$$

and

$$\alpha = \alpha_{class} + \alpha_{rot} + \frac{\omega}{2} \left(\frac{V}{V_{\infty}^2} \right) \operatorname{Im} \left[\frac{C_v^{\infty} + C_{vib}^{dyn}}{C_p^{\infty} + C_{vib}^{dyn}} \right]$$

where each contains a complex rational function of high order in $(j\omega)$. The separation into real and imaginary parts would yield an even more complicated fraction; however, for the convenience of the user, we have expressed $\left(C_v^{\infty} + C_{vib}\right) \Big/ \left(C_p^{\infty} + C_{vib}\right)$ in partial fractions by using a second main axis transformation. This yields

$$\left(\frac{k}{\omega} \right)^2 = \frac{\rho}{P} \frac{C_v^{\infty}}{C_p^{\infty}} \left(1 + \sum \frac{A_i}{1 + j\omega\tau_i^{ps}} \right) + \text{classical effects} + \text{rotational effects} \tag{10}$$

where the τ_i^{ps} differ slightly from the τ_i^{pt}, $A_i = \beta_i/\beta^{\infty}$, $\beta^{\infty} = \dfrac{C_v^{\infty}}{PC_p^{\infty}}$ and

$\sum A_i = (\beta^{o} - \beta^{\infty})/\beta^{\infty} = \sum \beta_i/\beta^{\infty} = \beta/\beta^{\infty}$ is closely related to the so-called relaxation strength of a single relaxation process $(\beta^{o} - \beta^{\infty})/\beta^{o} = \beta/\beta^{o}$. The A_i could be interpreted

as telling which part of the vibrationally relaxing adiabatic compressibility, β, is connected to the particular τ_i^{ps} (called isobaric-adiabatic or isobaric-isentropic relaxation time in Ref. 6). Using this notation, the separation of the imaginary and real parts of the propagation constant k can be accomplished to obtain

$$\frac{V_\infty^2}{V^2} = 1 + \sum \frac{A_i}{1 + (\omega\tau_i^{ps})^2} \tag{11}$$

and

$$\alpha = \alpha_{class} + \alpha_{rot} + \frac{\omega}{4}\left(\frac{V}{V_\infty^2}\right)\sum \frac{A_i\,\omega\,\tau_i^{ps}}{1 + (\omega\tau_i^{ps})^2} \quad . \tag{12}$$

IV. RESULTS

The 24 binary energy transfer rates defined in Ref. 1 were used to obtain relaxation times and strengths which were in turn inserted into Eqs. (11) and (12) of this paper to obtain the absorption and dispersion of sound in still air. To facilitate these calculations the rate $M0P_1^1$ (5,2,0) was changed to 7×10^5 sec^{-1} atm^{-1}. After this change the absorption results were within 3% of those published in Ref. 2 for all frequencies above 100 Hz. Below 100 Hz the two differ by as much as 15% for some humidities; however, this is not considered serious since below 100 Hz the values in Ref. 2 may be in error by as much as 50%. The difference in the $M0P_1^1$ (5,2,0) rate will be discussed in a subsequence publication. The eigenvalue analysis using the 24 rates yielded several relaxation times; however, only three of these had an associated relaxation heat or strength large enough to influence the absorption. As a result, instead of requiring 24 rates to describe the vibrational relaxation absorption as in Ref. 1,

only three relaxation times and strengths are needed at each humidity. In addition, the strengths are very nearly independent of humidity. For 20°C, the relaxation times and strengths are presented in Figs. 1 and 2. It is not possible to associate a relaxation time to a specific component of the atmosphere; however, examination of the contributions to the adiabatic compressibility shows that τ_1^{ps} is closely related to the relaxation of N_2 and τ_2^{ps} to O_2. These relaxation times should be considered only as useful computational parameters, and no attempt should be made to ascribe fundamental physical significance to them. The fundamental quantities are the binary rate constants.

Using Eq. (12), adding the various absorption terms, and combining constants gives the results in dB/1000 ft

$$\alpha = 27.26 \left\{ \sum_{i=1}^{4} \frac{f\, T_i\, A_i}{1 + f^2 T_i^2} + 1.525 \times 10^{-9}\, f \right\} \frac{f}{c} \qquad (13)$$

The values of (T_1, T_2, T_3) and (A_1, A_2, A_3) can be taken from Figs. 1 and 2 respectively or calculated using

$$\log_e (T_i \text{ or } A_i) = b_0 + b_1 (\log_e H) + b_2 (\log_e H)^2 + b_3 (\log_e H)^3 \qquad (14)$$

where the regression coefficients are given in Table I. A_4 is defined to be unity, $T_4 = 6.5 \times 10^{-10}$ sec and c is calculated by

$$c = \frac{1}{30480} \left[\left(\frac{3.5 + 5h}{2.5 + 5h} \right) \frac{8.3166 \times 10^7\, \theta}{28.966 - 10.95h} \right]^{1/2} \qquad (15)$$

where $h = P_w H/100$.

For computational convenience c may be set equal to 1.13 if an empirically derived $T_4 = 5 \times 10^{-10}$ sec is used. This will also reproduce the tables of Ref. 2 within 3%. During any of these calculations it must be remembered, that the frequency divided by the pressure, not the actual acoustic frequency is the important variable. Hence, a decrease in pressure is equivalent to an increase in frequency. For calculations at pressures other than one standard atmosphere, f/p should be inserted at all places f presently appears except outside the brackets in Eq. (13).

V. SUMMARY

A set of equations has been developed which will accurately predict the absorption of sound in still air at 20°C over the frequency range of 12 Hz - 1 MHz and over all humidities. The method of calculation presented was devised primarily as a computational convenience. The accuracy of the calculations is still limited, as was noted in Ref. 1 by limited knowledge of the binary energy transfer rates, but not by the computational method. Specifically, this lack of knowledge limits the accuracy of low frequency (12 Hz to 60 Hz) calculations which might be off as much as a factor of 2 due to the lack of knowledge about CO_2/O_2 V-V energy transfer. The ability to apply this formalism at other temperatures is also severely limited by lack of knowledge about the temperature dependence of the CO_2/O_2 rates and those rates involving H_2O as a collision partner. Nevertheless, the problem of sound absorption in still air has been simplified while maintaining a correct physical formalism. The temperature dependence and low frequency problems will be solved as soon as binary rate data is available.

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TABLE I. Regression Coefficients for Eq. 14.

	b_0	b_1	b_2	b_3
T_1	- 2.357009	-0.5423307	-0.05253065	-0.0006430596
T_2	- 5.388992	-1.231140	-0.04769421	0.004000068
T_3	- 9.780594	-0.8459473	-0.03399849	0.002532959
A_1	- 8.974335	-0.003204346	-0.0004720688	-0.0001525879
A_2	- 7.397324	0.006179810	0.0001125336	-0.00001049042
A_3	-10.40355	0.01698303	-0.002468109	-0.0002794266

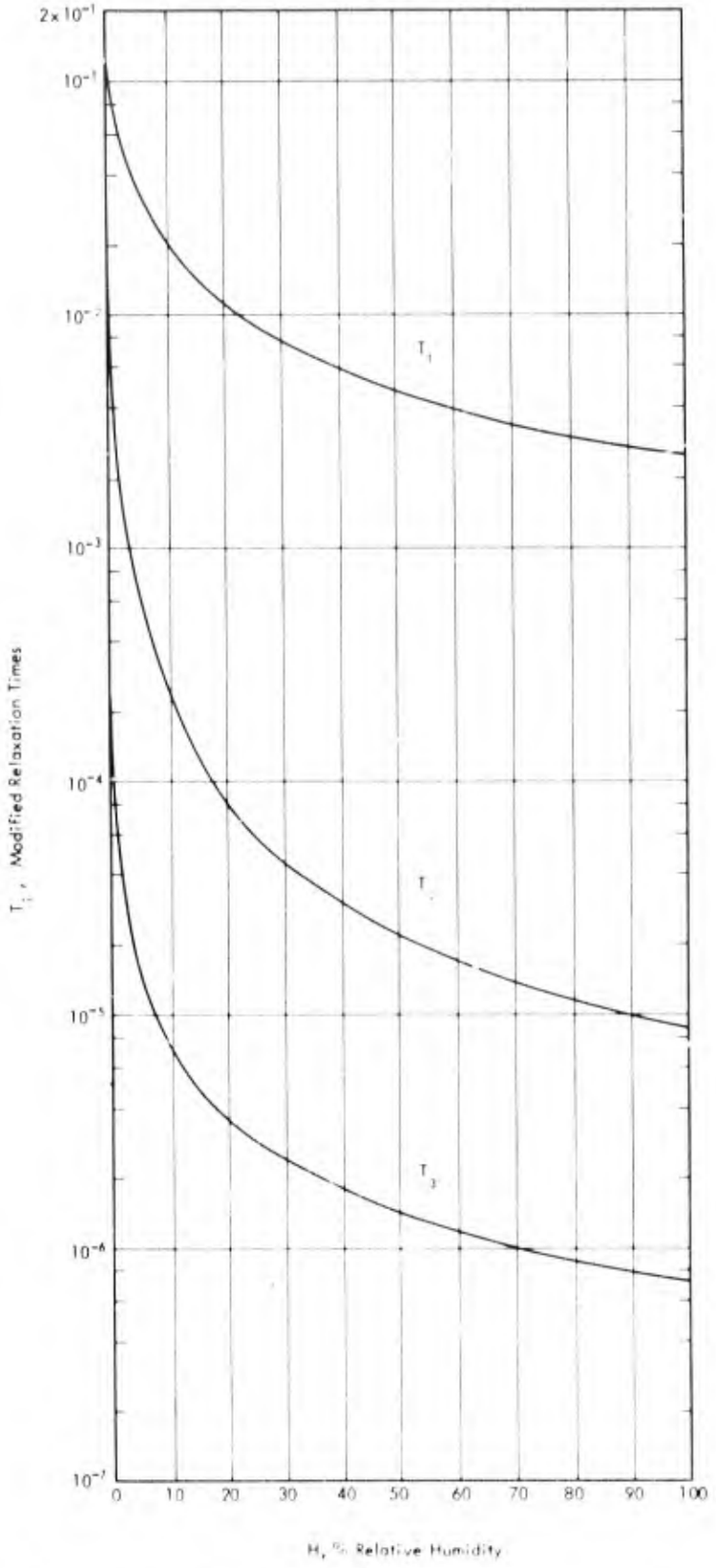

Figure 1. Modified Relaxation Times T_1, T_2 and T_3 as a Function of Percent Relative Humidity.

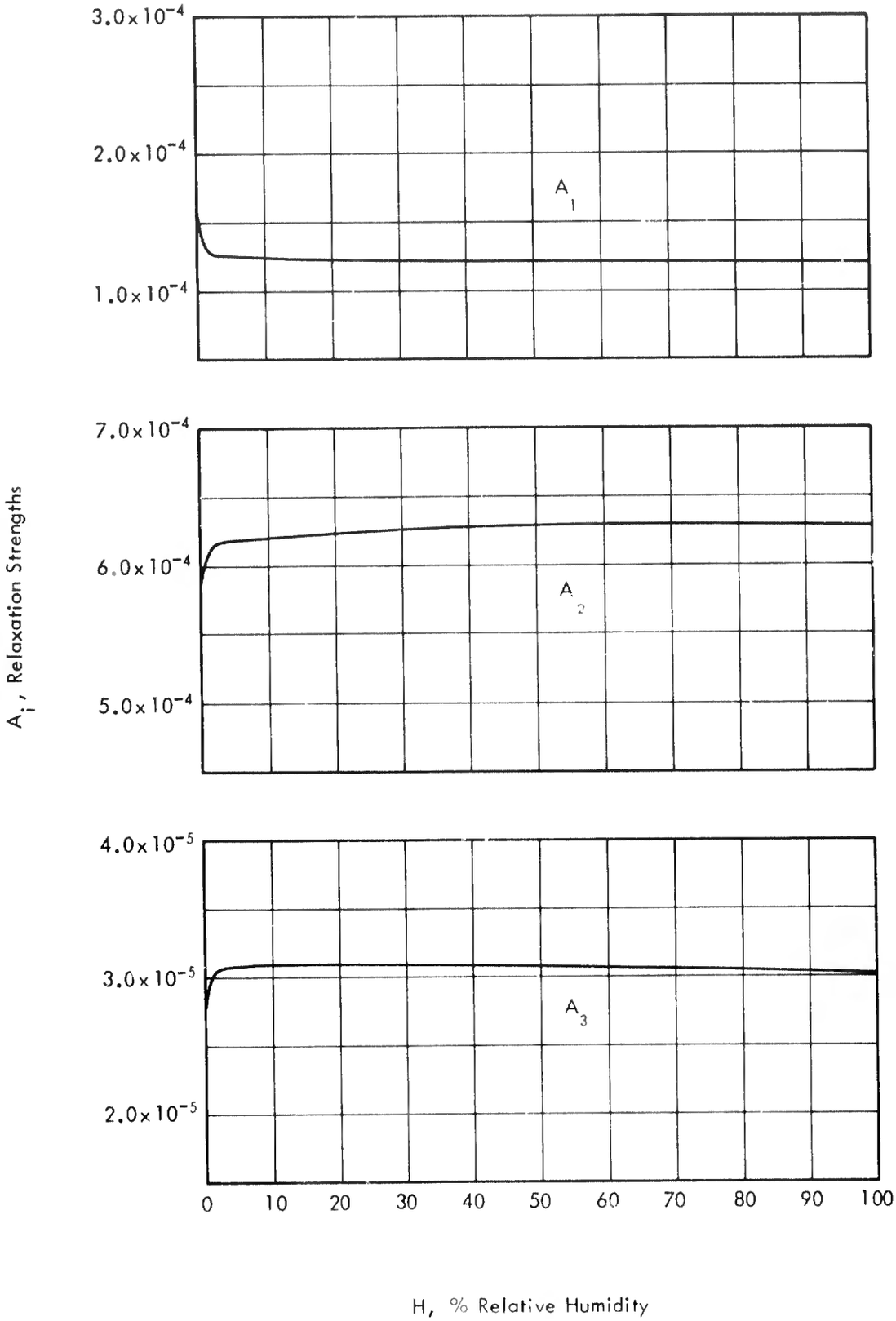

Figure 2. Derived Relaxation Strengths A_1, A_2 and A_3 as a Function of Percent Relative Humidity.

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13 ABSTRACT

Tables are presented for the absorption and velocity of sound in still air at 68° F (20° C). The absorption is presented in dB/1000 ft, dB/Km, and dB/sec. The velocity is presented in 1000 ft/sec. The tables cover the frequency range of 12 Hz - 1 MHz and for relative humidities of 0% - 100%. An appendix is included which presents analytical expressions that will duplicate the tables within 3% over all frequencies and humidities.

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14 KEY WORDS	LINK A		LINK B		LINK C	
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Atmospheric Absorption of Sound						
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