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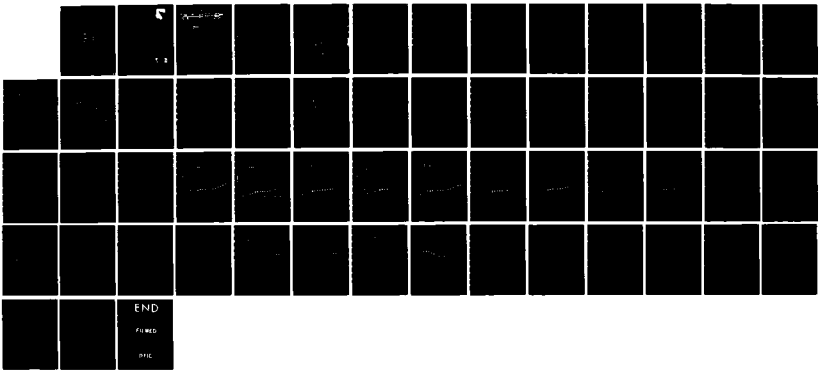

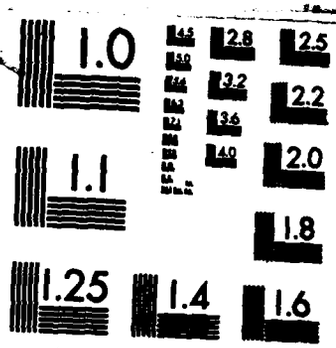

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Volume 3

OVERGROUND EXCESS SOUND ATTENUATION (ESA)

VOLUME 3. APPLICATION OF ESA DATA IN NOISEFILE

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AFAMRL-TR-84-017, Vol. [illegible]

This report has been reviewed by the Office of Public Affairs (PA) and is [illegible] National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

Henning E. von Gierke

HENNING E. VON GIERKE, Dr Ing
Director
Biodynamics and Bioengineering Division
Air Force Aerospace Medical Research Laboratory

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This is the third report in the series concerning Overground Excess Attenuation, ESA. Different models and algorithms for computing ESA are compared in terms of differences in A-levels at varying distances for different aircraft noise spectra. ESA values from recent field measurement at Wright-Patterson AFB, Dayton OH, theoretical models, and from NOISEMAP and a SAE recommendation are compared.

It is recommended that the current NOISEMAP ESA algorithms be replaced with ESA curves based on Dayton data acquired under moderate downwind propagation conditions. It is also recommended that additional ESA field data be acquired over irregular terrain where direct line-of-sight propagation does not exist. cont keywords include: —

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PREFACE

This research was performed for the Aerospace Medical Research Laboratory at Wright-Patterson Air Force Base, Ohio, under Project/Task 723107, Technology to Define and Assess Environmental Quality of Noise From Air Force Operations. Administration and technical monitors for this effort were Mr. Jerry D. Speakman and Mr. Robert G. Powell, respectively, both of the Biodynamic Environment Branch, Biodynamics and Bioengineering Division.

This study utilizes noise and meteorological data from the same Project/Task and Organization as listed above. The author gratefully acknowledges the guidance and helpful support of Mr. Robert Powell and Mr. Jerry Speakman and the assistance of Ms. Emma Wilby, BBN, who prepared and exercised the analytical model computer programs.

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1. INTRODUCTION

This report compares different models and algorithms for computing the excess sound attenuation for sound propagation over near-level terrain. On the basis of these comparisons and other considerations, the report provides recommendations for the excess sound attenuation algorithms incorporated in NOISEMAP calculations.

The comparisons of models are based upon differences in A-weighted sound levels at varying distances from aircraft with and without the excess sound attenuation adjustments applied. The excess sound attenuation adjustments for most models are applied to aircraft flyover 1/3 octave band noise spectra. These comparisons provide a basis for estimating the practical differences in the different models for computing excess sound attenuation.*

The excess attenuation data that were studied included curves derived from the recent excess attenuation measurements conducted at Wright-Patterson AFB [1],[2] and curves based upon theoretical ESA values using model parameters that provided a good fit between theory and the field experiments as well as the existing NOISEMAP model [3] and the SAE excess attenuation curve [4].

*The airport noise prediction models in widespread use in this country are based on the A-weighted sound level method (typically with single flyover noise events described in terms of the sound exposure level (SEL) and with day-night level (DNL) as the descriptor of the 24-hour noise environment).

Sections 2 and 3 of the report discuss the method of approach and summarize the comparisons. Section 4 discusses the results. The last section provides recommendations for the NOISEMAP programs.

This report describes an extension and an application of the work discussed in reference 2. The reader is referred to reference 2 for definition of many of the terms, and for details of the theoretical model utilized in this report.

2. METHOD OF APPROACH

As discussed in Ref. 2, the experimental ESA measurements (referred to herein as the Dayton measurements) have been analyzed to yield average values of excess attenuation for certain ranges of wind component speeds* and temperature gradient conditions. Further, theoretical predictions of excess sound attenuation over a flat surface of uniform impedance were found to provide a reasonable fit with the experimental data (for near neutral temperature conditions and near zero wind component conditions) for selected values of flow resistivity and atmospheric turbulence parameters in the theoretical model. Both the field data and theoretical calculations provide values of excess sound attenuation in 1/3 octave bands at different distances from the source.

In most NOISEMAP applications and in most practical community noise prediction applications as well, the noise measure of interest is the A-weighted sound level. Thus, it is of great practical interest to compare different ESA algorithms in terms of their influences on A-weighted noise level results that are not obtainable directly from either the field measurements or analytical studies.

The shape of the noise spectrum varies among aircraft and engine power settings at a given reference distance. The spectrum shape also varies significantly with distance from the aircraft due to air attenuation. Hence, the calculated differences in A-levels with and without excess attenuation adjustments applied to the noise spectrum may be expected to vary as a function of aircraft type, power setting, and distance. Thus, in comparing different ESA assumptions, the basic approach was to use the different sets of 1/3 octave band spectra versus distance data for different aircraft and to

*The wind component is taken as the magnitude of the wind speed in the direction of sound propagation.

compute differences in A-levels with and without the excess attenuations applied to the data. The resulting differences in A-levels could then be compared among aircraft.

2.1 Selection of Noise Spectra

Flyover noise vs distance data were selected to provide a variety of spectrum shapes representing noise levels produced by turbojet, turbofan, and turboprop aircraft at distances ranging from 200 to 25,000 ft. Eight spectrum sets were selected from those in Ref. 5, representing typical takeoff and approach levels for the C-135A (turbojet), C-9A (low bypass ratio turbofan), C-130H (turboprop), and F-16 (afterburner turbojet). A ninth spectrum set--that for the Challenger 600, a business aircraft powered with a high bypass ratio turbofan- was also selected. Figures 1 through 5 show the noise spectra for the different aircraft at a slant distance of 1000 feet*.

2.2 Selection of ESA Data

The special digital computer program (Omega 13) discussed in Ref. 1 provided capabilities for sorting the experimental ESA data for specified ranges of temperature gradient and wind component values. For each sort program, the program computed average values for each 1/3 octave band at the measured distances. The program also provided a regression curve** fitted to the data and computed ESA values at various specified distance intervals based on the fitted regression curve.

Three regression curve analyses were selected. All of the analyses represented over-ground propagation under neutral

---

* Reference 5 was chosen because it has a large volume of flyover noise data where the microphone was directly under the aircraft's flight path and data results are in terms of A-weighted levels with and without ESA added into them. An independent check by an AFAMRL scientist confirmed that conclusions and recommendations drawn in this report would have been the same had average ground-runup noise data (averaged around the aircraft) been used instead of flyover data.

** A fifth-order polynomial curve

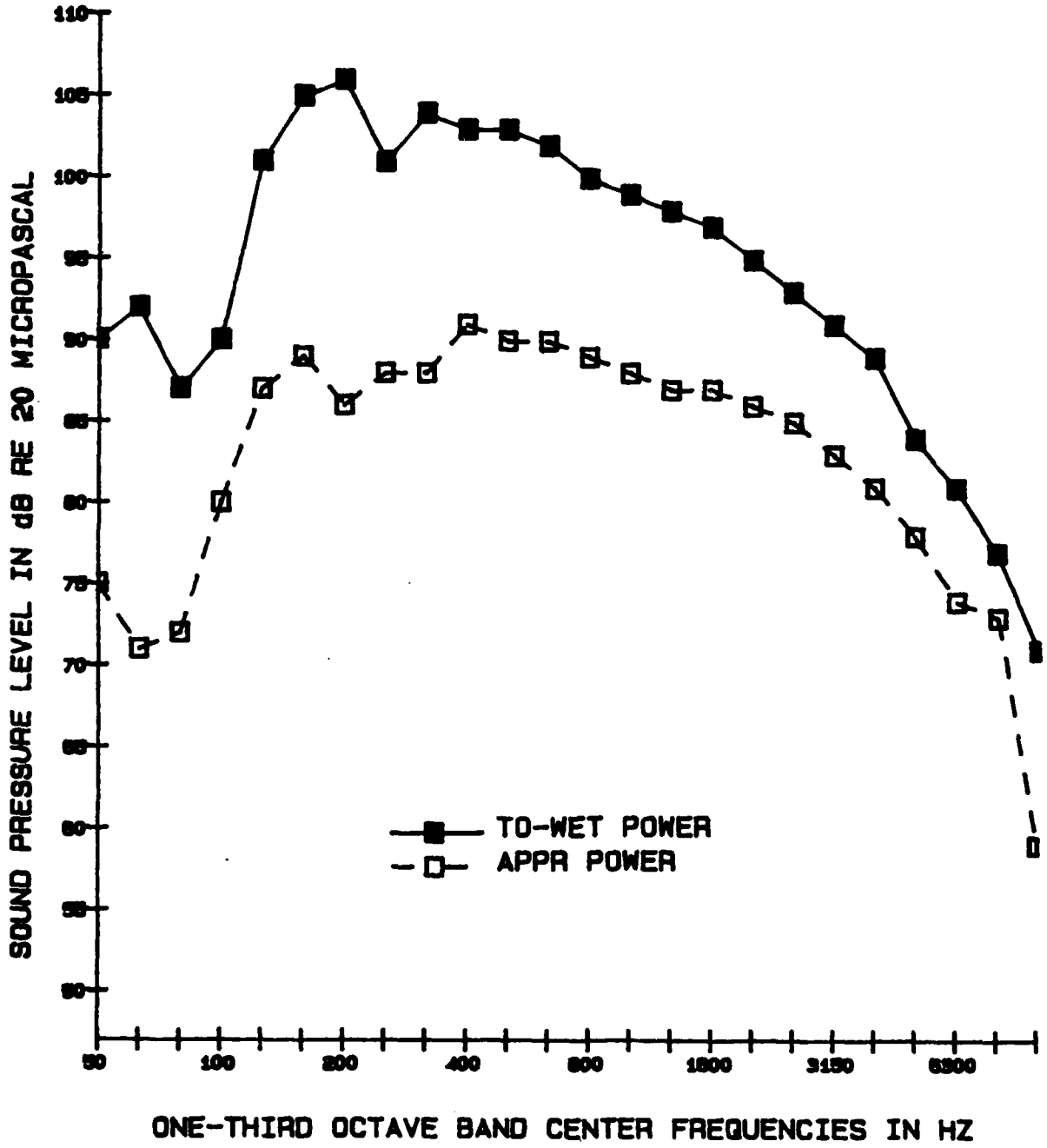


FIGURE 1. NOISE SPECTRA AT 1000 FT. DISTANCE - C-135A AIRPLANE

TABLE 3 - EXCESS SOUND ATTENUATION VALUES - THEORETICAL

A. Flow Resistivity of 150 CGS Rayls - Attenuation Relative to 250 ft. Measurement Position

THEORETICAL ESA-REL, R 150

FREQ	DISTANCE IN FEET																
HZ	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	6300	8000	10000
50	0	0	0.15	0.16	0.18	0.20	0.24	0.30	0.38	0.49	0.63	0.83	1.10	1.44	1.93	2.52	3.27
63	0	0	0.28	0.32	0.37	0.44	0.53	0.66	0.85	1.07	1.37	1.77	2.31	2.96	3.91	5.01	6.41
80	0	0	0.51	0.60	0.73	0.90	1.10	1.37	1.76	2.21	2.80	3.59	4.64	5.89	7.65	9.66	12.10
100	0	0	0.89	1.08	1.33	1.66	2.06	2.58	3.31	4.16	5.24	6.66	8.51	10.66	13.55	16.55	19.70
125	0	0	1.53	1.90	2.38	3.01	3.76	4.70	6.03	7.55	9.44	11.83	14.77	17.85	21.26	23.95	26.10
160	0	0	2.78	3.51	4.45	5.67	7.10	8.86	11.27	13.88	16.86	20.08	23.15	25.47	27.38	28.53	29.12
200	0	0	4.75	6.06	7.72	9.84	12.23	15.01	18.41	21.45	24.06	26.14	27.62	28.39	28.59	28.31	27.73
250	0	0	8.04	10.25	12.96	16.12	19.20	22.02	24.47	26.03	26.98	27.36	27.19	26.69	25.89	25.05	24.15
315	0	0	12.77	15.62	18.39	20.78	22.51	23.77	24.60	24.80	24.58	24.01	23.21	22.36	21.36	20.42	19.47
400	0	0	13.67	15.43	17.14	18.73	19.97	20.83	21.26	21.18	20.75	20.06	19.19	18.30	17.28	16.33	15.38
500	0	0	11.28	12.96	14.67	16.33	17.69	18.73	19.38	19.49	19.20	18.60	17.79	16.93	15.93	14.99	14.05
630	0	0	8.75	10.47	12.24	14.00	15.49	16.74	17.68	18.05	17.97	17.53	16.82	16.01	15.04	14.13	13.21
800	0	0	6.07	7.81	9.61	11.42	13.00	14.38	15.53	16.12	16.24	15.96	15.35	14.61	13.68	12.80	11.90
1000	0	0	3.12	4.86	6.67	8.51	10.14	11.59	12.87	13.59	13.86	13.70	13.18	12.50	11.61	10.76	9.88
1250	0	0	0	0.67	2.47	4.31	5.96	7.46	8.82	9.64	10.02	9.96	9.52	8.89	8.05	7.23	6.38
1600	0	0	0	0	0.35	2.18	3.84	5.36	6.77	7.68	8.15	8.18	7.82	7.25	6.46	5.68	4.86
2000	0	0	0	0	2.08	3.88	5.52	7.05	8.49	9.45	9.98	10.09	9.80	9.28	8.54	7.79	7.00
2500	0	0	0	0	1.36	3.10	4.71	6.23	7.69	8.68	9.28	9.45	9.24	8.77	8.07	7.35	6.58
3150	0	0	0	0	0	0	0.98	2.47	3.92	4.95	5.60	5.84	5.69	5.28	4.62	3.93	3.17
4000	0	0	0	0	0	0	0	0	0.81	1.85	2.55	2.86	2.78	2.41	1.78	1.09	0.34

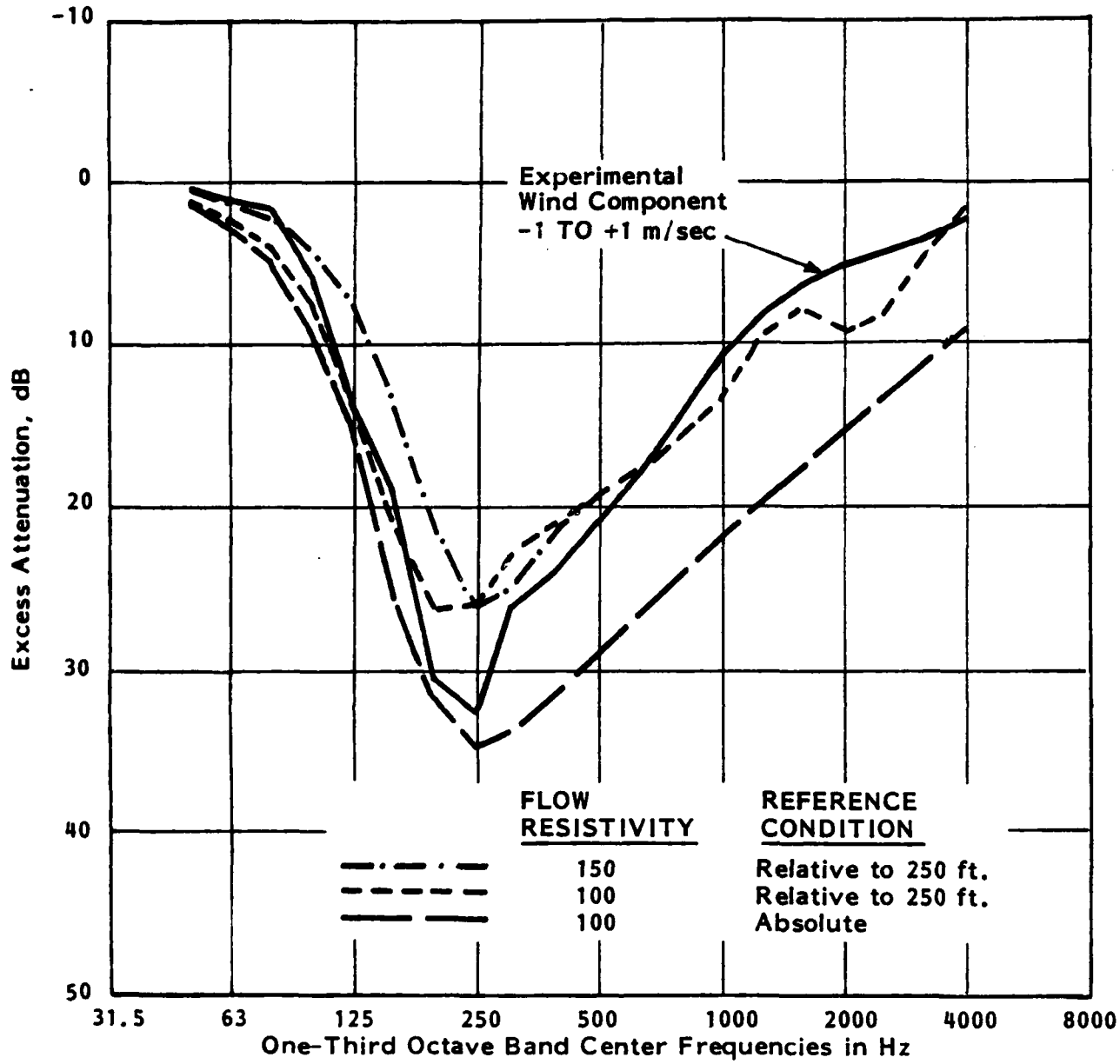


FIGURE 8. COMPARISON OF THEORETICAL ESA VALUES AT 2000 FT. DISTANCE FROM SOURCE

reference position of 250 feet. This is consistent with the approach used in comparing theory with field data in reference 2.

A third set of theoretical ESA values, the ESA values for a flow resistivity of 100 cgs rayls, was calculated in terms of differences re a hard surface. This assumes that the reference measurements were all made above a hard surface, and are now to be applied to estimate noise levels, at 250 ft distance and greater, above a grassy surface.

The three sets of theoretical ESA values are tabulated in Table 3. A comparison of these ESA values at a distance of 2000 feet is shown in Fig. 8.

Each of the above seven sets of ESA values is frequency-dependent. A-level differences obtained by use of these ESA sets were also compared with the SAE ESA curve (ref. 4) which is <u>not</u> frequency-dependent.

TABLE 2 - EXCESS SOUND ATTENUATION VALUES - NOISEMAP*

NOISEMAP ESA

FREQ	DISTANCE IN FEET																
HZ	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	6300	8000	10000
50	0	0	0	0	0	0	0	0	0	1.18	2.66	4.58	7.09	10.05	13	13	13
63	0	0	0	0	0	0	0	0	1.27	2.73	4.55	6.91	10.00	12.50	15	15	15
80	0	0	0	0	0	0	0	1.00	2.40	4.00	6.00	8.60	12.00	13.50	17	17	17
100	0	0	0	0	0	0.42	1.17	2.33	3.82	5.52	7.64	10.39	14.00	16.50	19	19	19
125	0	0	0	0	0.56	1.29	2.14	3.21	4.71	6.43	8.57	11.36	15.00	17.50	20	20	20
160	0	0	0	0	0.56	1.29	2.14	3.21	4.71	6.43	8.57	11.36	15.00	17.50	20	20	20
200	0	0	0	0	0.56	1.29	2.14	3.21	4.71	6.43	8.57	11.36	15.00	17.50	20	20	20
250	0	0	0	0	0.56	1.29	2.14	3.21	4.71	6.43	8.57	11.36	15.00	17.50	20	20	20
315	0	0	0	0	0	0	0	0.85	2.04	3.40	5.10	7.31	10.20	13.60	17	17	17
400	0	0	0	0	0	0	0	0	0	0	1.38	3.16	5.50	8.25	11	11	11
500	0	0	0	0	0	0	0	0	0	0	0	0.93	2.14	3.57	5	5	5
630	0	0	0	0	0	0	0	0	0	0	0	0	0.60	1.80	3	3	3
800	0	0	0	0	0	0	0	0	0	0	0	0	0	0.33	1	1	1
1000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1250	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1600	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3150	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

* In current NOISEMAP computation, the values listed in the table are applied to ground runup data. For over-ground propagation of flyover noise, an additional 5 dB is added to all values in the table.

TABLE 1 - (Continued)

C. Wind Component Range - +1 to +3 meter/s (+2.3 to 6.7 mph)

DAYTON ESA WV +1 TO +3

FREQ	DISTANCE IN FEET																
HZ	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	6300	8000	10000
50	0	0	0.93	0.72	0.45	0.12	-0.25	-0.66	-1.16	-1.60	-1.99	-2.20	-2.1	-1.65	-1.27	-1.27	-1.27
63	0	0	1.41	1.19	0.90	0.54	0.15	-0.29	-0.81	-1.25	-1.57	-1.61	-1.13	-0.08	.98	0.98	.98
80	0	0	0.44	0.26	0.05	-0.20	-0.46	-0.72	-0.98	-1.11	-1.03	-0.56	0.53	2.15	3.79	3.79	3.79
100	0	0	1.53	1.36	1.17	1.01	0.89	0.86	1.01	1.41	2.15	3.34	5.02	6.75	8.05	8.05	8.05
125	0	0	2.16	2.29	2.49	2.79	3.21	3.83	5.13	5.99	7.54	9.47	11.55	13.00	13.12	13.12	13.12
160	0	0	2.29	3.50	4.97	6.71	8.53	10.48	12.67	14.57	16.22	17.55	18.51	19.13	19.13	19.13	19.13
200	0	0	4.44	6.85	9.69	12.93	16.10	19.20	22.19	24.10	24.90	24.45	23.22	22.76	22.76	22.76	22.76
250	0	0	11.69	13.63	15.90	18.46	20.94	23.30	25.48	26.69	26.88	25.90	24.18	23.18	23.18	23.18	23.18
315	0	0	13.06	14.58	16.39	18.25	18.67	19.02	19.25	19.21	18.88	18.23	17.38	16.74	16.18	15.62	15.06
400	0	0	10.71	12.28	14.13	15.58	15.93	16.22	16.42	16.41	16.16	15.66	14.97	14.33	13.5	12.67	11.84
500	0	0	8.74	10.23	12.00	12.50	12.64	12.75	12.77	12.67	12.39	11.92	11.25	10.53	9.57	8.61	7.65
630	0	0	7.33	8.64	9.38	9.33	9.24	9.13	8.94	8.71	8.40	7.97	7.40	6.72	5.82	4.92	4.02
800	0	0	5.39	6.48	6.58	6.54	6.45	6.32	6.08	5.77	5.34	4.84	4.31	3.88	3.26	2.64	2.02
1000	0	0	3.09	3.93	4.25	4.30	4.31	4.28	4.17	3.96	3.63	3.17	2.60	2.06	1.37	0.68	-0.01
1250	0	0	1.31	2.06	2.50	2.78	3.03	3.24	3.36	3.31	3.03	2.46	1.59	0.65	-.36	-1.37	-2.38
1600	0	0	0.16	0.86	1.71	2.69	3.10	3.11	3.02	2.81	2.42	1.76	0.76	-0.48	-2.09	-3.70	-5.31
2000	0	0	-1.58	-0.94	-0.15	0.80	1.81	2.80	2.71	2.43	1.87	0.91	-0.57	-2.46	-4.35	-6.24	-8.13
2500	0	0	-1.34	-0.75	-0.03	0.84	1.75	2.71	2.57	2.39	2.01	1.37	-0.39	-0.87	-2.13	-3.39	-4.65
3150	0	0	0.53	1.03	1.67	1.55	2.03	2.51	2.44	2.34	2.17	1.84	1.34	0.71	0.08	-0.55	-1.18
4000	0	0	1.92	2.03	2.15	2.25	2.30	2.30	2.30	2.30	2.30	2.30	2.30	2.30	2.30	2.30	2.30

TABLE 1 - (Continued)

B. Wind Component Range - -1 to +1 meter/s (-2.3 to +2.3 mph)

DAYTON ESA WV -1 TO +1

FREQ	DISTANCE IN FEET																
HZ	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	6300	8000	10000
50	0	0	0.97	0.95	0.93	0.87	0.79	0.69	0.52	0.32	0.12	0	0	0	0	0	0
63	0	0	1.43	1.42	1.40	1.36	1.30	1.23	1.13	1.03	0.97	1.03	1.39	2.17	3.35	3.46	3.46
80	0	0	0.46	0.59	0.75	0.93	1.11	1.30	1.50	1.70	1.95	2.37	3.19	4.53	6.29	6.29	6.29
100	0	0	0.90	1.39	1.97	2.67	3.39	4.17	5.06	5.86	6.63	7.44	8.42	9.69	11.24	11.24	11.24
125	0	0	1.19	2.47	4.01	5.83	7.68	9.62	11.73	13.41	14.69	15.44	15.67	15.86	16.89	18.23	18.23
160	0	0	2.31	4.74	7.63	10.99	14.36	17.79	21.33	19.53	25.36	25.47	25.47	25.47	25.47	25.47	25.47
200	0	0	7.49	10.09	13.19	16.79	20.44	24.17	28.05	30.90	32.61	32.78	32.78	32.78	32.78	32.78	32.78
250	0	0	14.08	16.36	19.05	22.14	25.17	28.17	31.09	32.92	33.54	33.54	33.54	33.54	33.54	33.54	33.54
315	0	0	13.06	14.58	16.39	18.49	20.56	22.64	24.69	26.02	26.54	26.54	26.54	26.54	26.54	26.54	26.54
400	0	0	10.71	12.28	14.13	16.27	18.40	20.54	22.67	24.09	24.69	24.69	24.69	24.69	24.69	24.69	24.69
500	0	0	8.74	10.23	12.00	14.04	16.07	18.09	20.11	21.45	22.01	22.01	22.01	22.01	22.01	22.01	22.01
630	0	0	7.33	8.64	10.19	11.97	13.73	15.49	17.23	18.36	18.81	18.81	18.81	18.81	18.81	18.81	18.81
800	0	0	5.39	6.48	7.79	9.30	10.81	12.32	13.85	14.87	15.34	15.34	15.34	15.34	15.34	15.34	15.34
1000	0	0	3.09	3.93	4.93	6.11	7.30	8.54	9.85	10.82	11.41	11.41	11.41	11.41	11.41	11.41	11.41
1250	0	0	1.31	2.06	2.95	4.01	5.09	6.22	7.44	8.37	9.00	9.14	9.14	9.14	9.14	9.14	9.14
1600	0	0	0.16	0.86	1.71	2.69	3.69	4.74	5.82	6.66	7.18	7.23	7.23	7.23	7.23	7.23	7.23
2000	0	0	-1.58	-0.94	-0.15	0.80	1.81	2.91	4.16	5.22	6.02	6.34	6.34	6.34	6.34	6.34	6.34
2500	0	0	-1.34	-0.75	-0.03	0.84	1.75	2.71	3.76	4.56	4.99	4.99	4.99	4.99	4.99	4.99	4.99
3150	0	0	0.53	1.03	1.67	1.55	2.03	2.51	3.03	3.65	3.65	3.65	3.65	3.65	3.65	3.65	3.65
4000	0	0	1.92	2.03	2.15	2.25	2.30	2.30	2.30	2.30	2.30	2.30	2.30	2.30	2.30	2.30	2.30

TABLE 1 - EXCESS SOUND ATTENUATION VALUES - DERIVED FROM DAYTON FIELD MEASUREMENTS

A. Wind Component Range - -3 to -1 meter/s (-6.7 to -2.3 mph)

DAYTON ESA WV -1 TO -3

FREQ	DISTANCE IN FEET																
HZ	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	6300	8000	10000
50	0	0	2.44	2.47	2.54	2.68	2.91	3.28	3.92	4.75	5.87	7.28	8.84	10.05	10.93	10.93	10.93
63	0	0	2.85	3.03	3.25	3.56	3.93	4.42	5.14	5.99	7.07	8.48	10.22	12.02	13.71	14.51	14.51
80	0	0	1.50	1.69	1.95	2.31	2.77	3.40	4.34	5.48	6.98	8.93	11.37	13.86	16.18	17.60	17.60
100	0	0	1.57	1.97	2.47	3.11	3.83	4.69	5.88	7.20	8.84	11.01	13.93	17.30	20.70	20.70	20.70
125	0	0	2.20	2.98	3.95	5.12	6.37	7.77	9.49	11.20	13.09	15.37	18.33	21.91	25.74	25.74	25.74
160	0	0	3.37	5.00	6.94	9.20	11.49	13.87	16.48	18.63	20.50	22.24	24.34	27.41	31.40	31.40	31.40
200	0	0	5.24	8.11	11.47	15.32	19.11	22.87	26.61	29.23	30.83	31.50	32.06	34.07	37.12	37.12	37.12
250	0	0	8.75	11.73	15.26	19.31	23.31	27.28	31.24	33.91	35.31	35.24	35.24	35.24	35.24	35.24	35.24
315	0	0	11.24	13.75	16.69	20.01	23.22	26.31	29.20	30.91	31.45	31.45	31.45	31.45	31.45	31.45	31.45
400	0	0	13.98	15.70	17.84	20.28	22.66	25.00	27.25	28.69	29.30	29.30	29.30	29.30	29.30	29.30	29.30
500	0	0	13.08	14.58	16.34	18.35	20.32	22.27	24.17	25.44	26.06	26.06	26.06	26.06	26.06	26.06	26.06
630	0	0	11.82	13.16	14.75	16.56	18.33	20.08	21.78	22.91	23.45	23.45	23.45	23.45	23.45	23.45	23.45
800	0	0	10.68	11.86	13.25	14.87	16.47	18.08	19.70	20.81	21.42	21.42	21.42	21.42	21.42	21.42	21.42
1000	0	0	9.85	10.87	12.07	13.47	14.88	16.32	17.81	18.91	19.59	19.73	19.73	19.73	19.73	19.73	19.73
1250	0	0	10.35	11.28	12.38	13.67	14.97	16.30	17.70	18.74	19.41	19.57	19.57	19.57	19.57	19.57	19.57
1600	0	0	9.47	10.40	11.50	12.77	14.03	15.31	13.61	17.52	18.02	18.02	18.02	18.02	18.02	18.02	18.02
2000	0	0	7.56	8.42	9.43	10.50	11.78	12.96	14.17	15.03	15.52	15.52	15.52	15.52	15.52	15.52	15.52
2500	0	0	7.66	8.38	9.25	10.27	11.31	12.38	13.49	14.26	14.59	14.59	14.59	14.59	14.59	14.59	14.59
3150	0	0	7.51	8.67	10.02	11.53	12.97	14.27	15.28	15.44	15.44	15.44	15.44	15.44	15.44	15.44	15.44
4000	0	0	7.51	8.67	10.02	11.53	12.97	14.27	15.28	15.44	15.44	15.44	15.44	15.44	15.44	15.44	15.44

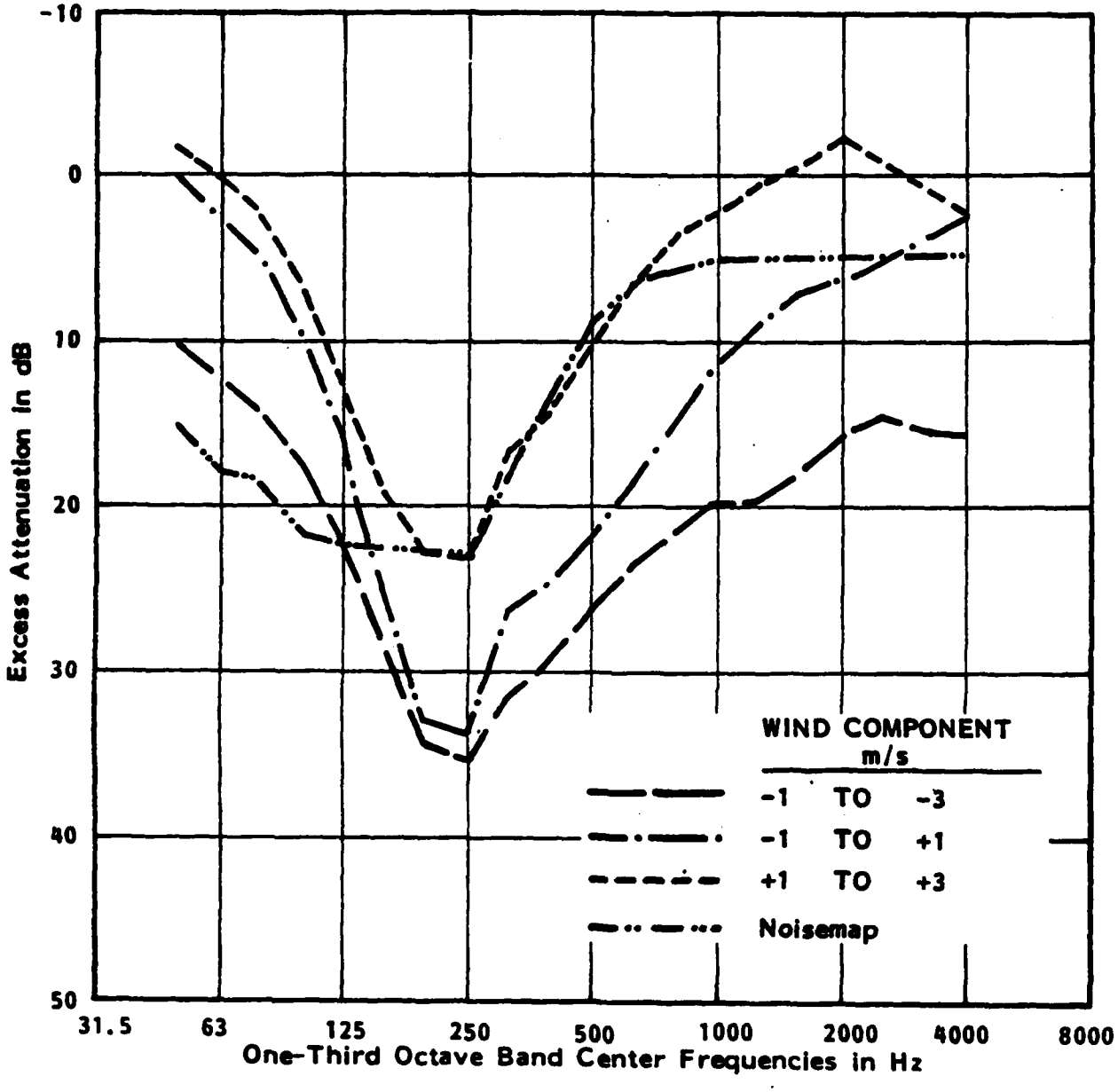


FIGURE 7. COMPARISON OF EXPERIMENTAL ESA VALUES AT 5000 FT. DISTANCE FROM SOURCE

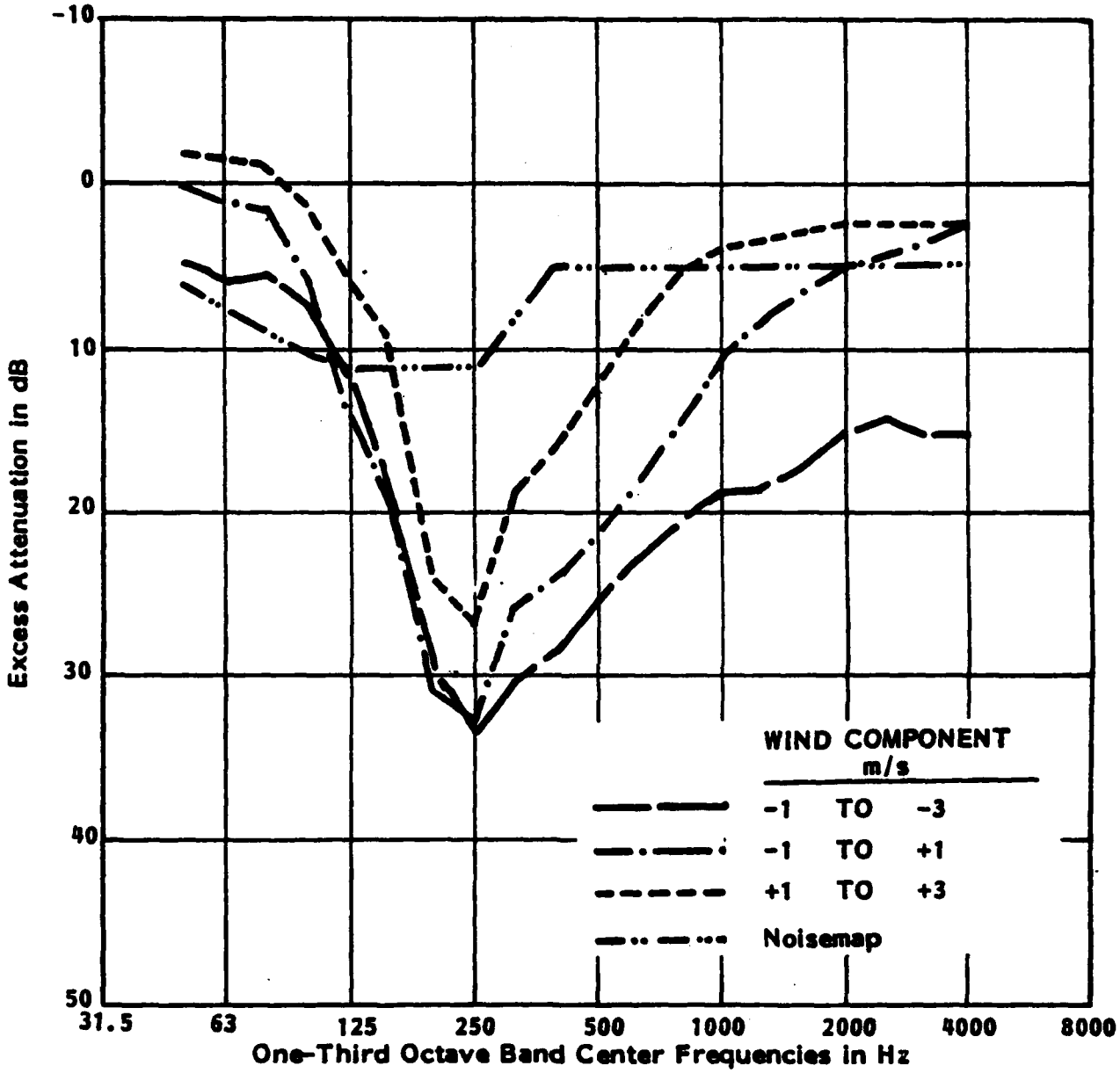


FIGURE 6. COMPARISON OF EXPERIMENTAL ESA VALUES AT 2000 FT. DISTANCE FROM SOURCE

temperature gradient conditions. Three ranges of wind component values were selected:

-3 to -1 m/s (-6.7 to -2.2 mph)
-1 to +1 m/s (-2.2 to +2.2 mph)
+1 to +3 m/s (+2.2 to +6.7 mph)

These three sets of wind conditions were selected to cover a range of wind conditions spanning moderate upwind to moderate downwind propagation.

A fourth set of ESA curves is represented by the current NOISEMAP algorithms (ref 3). The NOISEMAP algorithms plus the three ESA curves derived from the Dayton field measurements represent excess attenuation curves derived from field measurements. The ESA values for these four sets are tabulated in Tables 1 and 2. Plots of the ESA values at distances of 2000 and 5000 feet are shown in Figure 6 and 7.

Three sets of theoretical ESA values were computed* based upon two sets of parameters that had been found to provide a reasonable fit with the experimental Dayton data as discussed in reference 2. Flow resistivity values of 100 and 150 cgs rayls were assumed. Turbulent atmosphere parameters of fluctuating index of refraction of 1×10^{-7} and amplitude phase covariance values of 0.85 were assumed.

For both flow resistivity values, ESA values were computed in terms of the difference in ESA with respect to measurements at a reference measuring position at 250 feet from the aircraft source. This assumes, in essence, that no excess sound attenuation occurred between the aircraft and the

* The theoretical model is described in Appendix A of Reference 2.

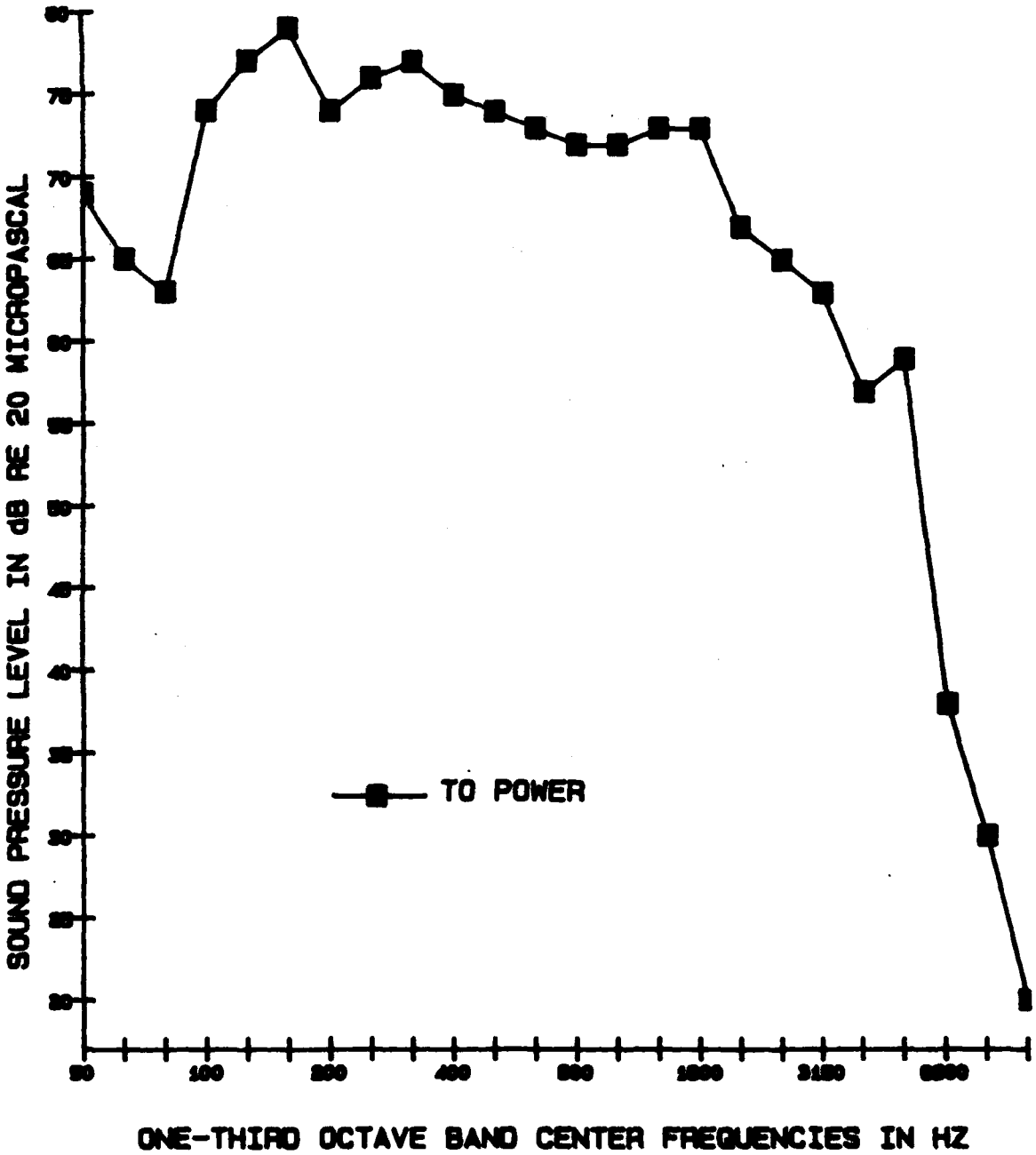


FIGURE 5. NOISE SPECTRA AT 1000 FT. DISTANCE - CHALLENGER 600 AIRPLANE

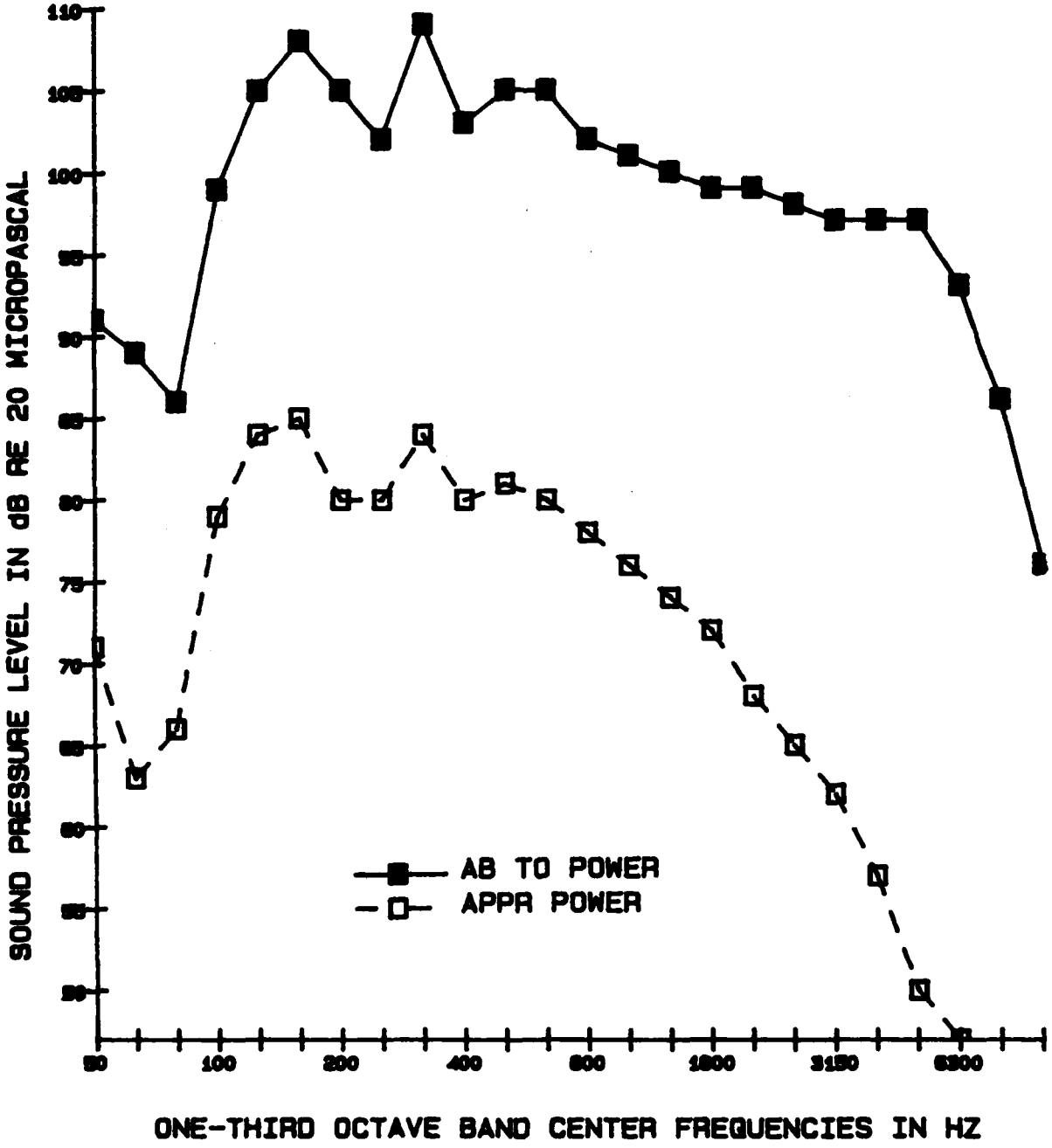


FIGURE 4. NOISE SPECTRA AT 1000 FT. DISTANCE - F-16 AIRPLANE

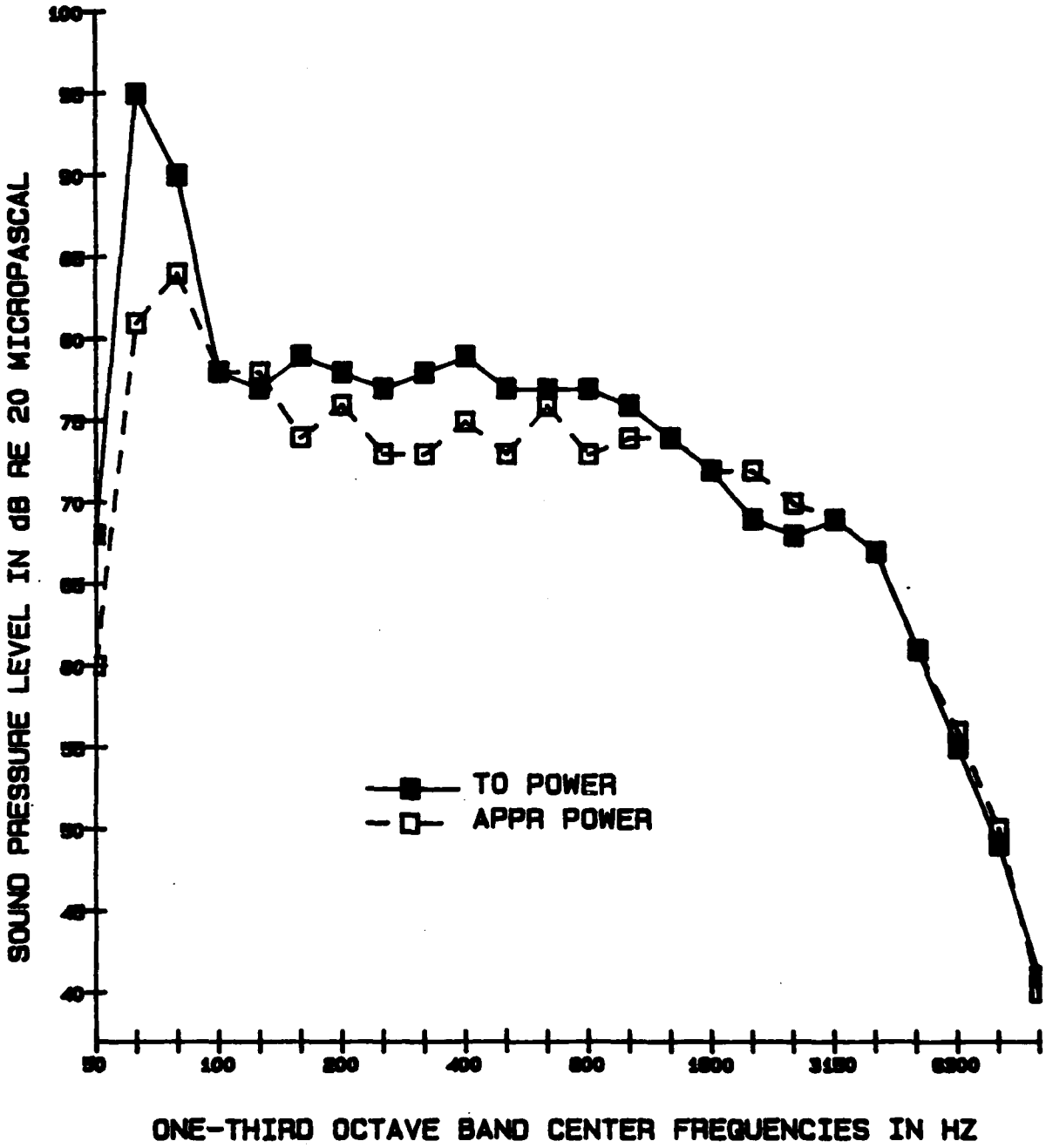


FIGURE 3. NOISE SPECTRA AT 1000 FT. DISTANCE - C-130 H AIRPLANE

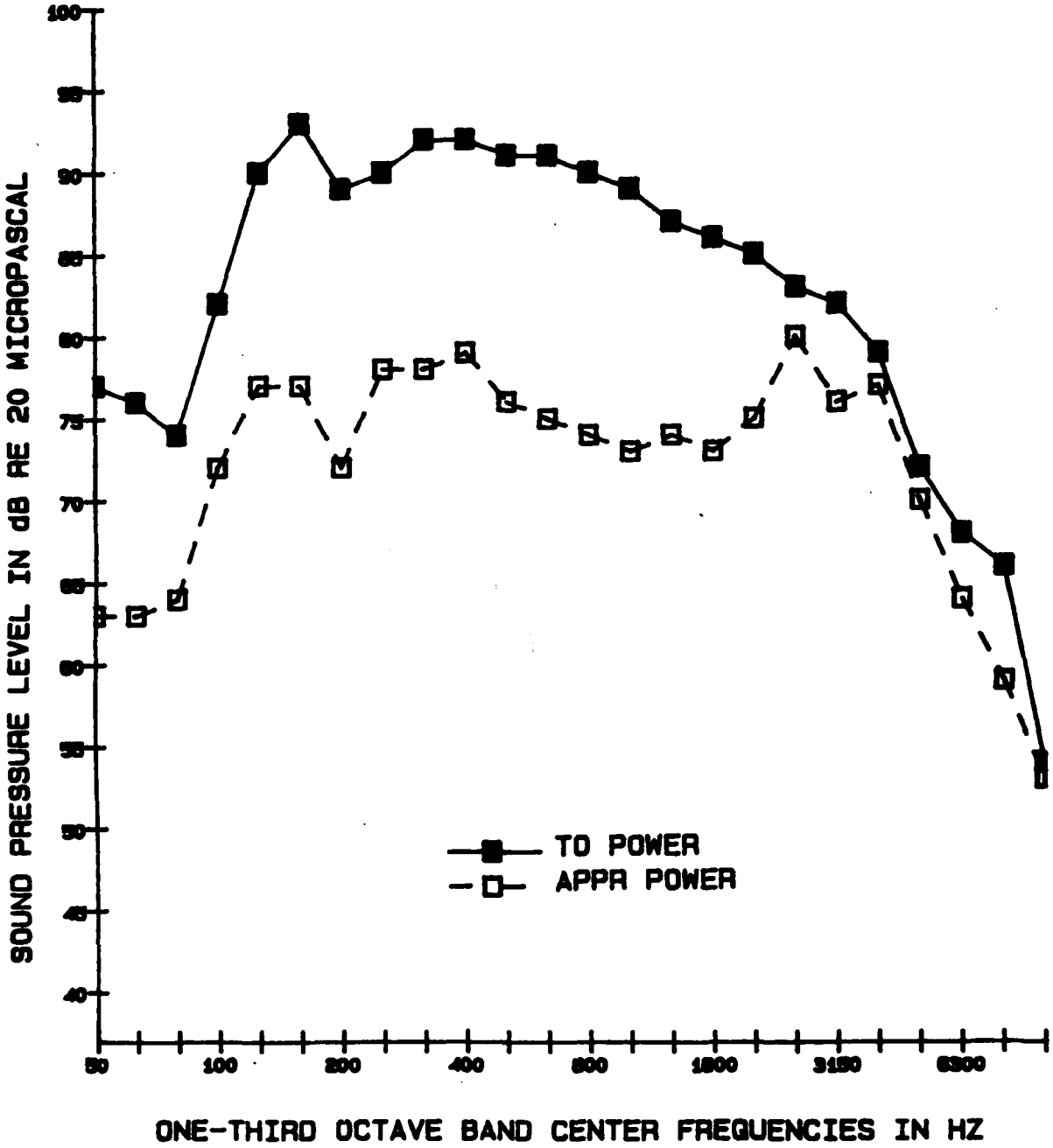


FIGURE 2. NOISE SPECTRA AT 1000 FT. DISTANCE - C-9 AIRPLANE

TABLE 3 - EXCESS SOUND ATTENUATION VALUES - THEORETICAL

B. Flow Resistivity of 100 CGS Rayls - Attenuation Relative to 250 Ft. Measurement Position

THEORETICAL ESA-REL. R 100

FREQ	DISTANCE IN FEET																
Hz	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	6300	8000	10000
50	0	0	0.26	0.30	0.35	0.42	0.52	0.65	0.84	1.07	1.38	1.79	2.34	3.02	3.99	5.12	6.54
63	0	0	0.47	0.56	0.69	0.85	1.06	1.33	1.72	2.18	2.77	3.55	4.60	6.86	7.62	9.63	12.06
80	0	0	0.87	1.06	1.32	1.67	2.09	2.62	3.39	4.28	5.40	6.87	8.79	11.01	13.96	17.00	20.15
100	0	0	1.51	1.88	2.38	3.03	3.01	4.79	6.16	7.73	9.68	12.13	15.12	18.21	21.60	24.28	26.50
125	0	0	2.60	3.30	4.20	5.39	6.77	8.48	10.81	13.36	16.27	19.49	22.64	25.15	27.38	28.95	30.03
160	0	0	4.72	6.04	7.73	9.88	12.29	15.08	18.47	21.49	24.14	26.37	28.13	29.26	29.86	29.87	29.48
200	0	0	7.99	10.21	12.91	16.07	19.13	21.98	24.59	26.40	27.71	28.48	28.67	28.39	27.73	26.97	26.10
250	0	0	12.66	15.57	18.49	21.10	23.07	24.62	25.79	26.30	26.32	25.92	25.23	24.43	23.45	22.53	21.58
315	0	0	14.75	16.67	18.49	20.17	21.48	22.42	22.92	22.90	22.50	21.83	20.97	20.09	19.07	18.12	17.17
400	0	0	12.66	14.37	16.10	17.77	19.12	20.14	20.77	20.85	20.54	19.92	19.10	18.23	17.22	16.20	15.33
500	0	0	10.42	12.16	13.94	15.70	17.18	18.39	19.28	19.60	19.49	19.01	18.27	17.45	16.47	15.54	14.61
630	0	0	8.13	9.89	11.70	13.52	15.09	16.45	17.56	18.10	18.18	17.85	17.21	16.45	15.50	14.60	13.69
800	0	0	5.64	7.41	9.24	11.09	12.72	14.17	15.42	16.13	16.36	16.17	15.62	14.92	14.01	13.14	12.24
1000	0	0	2.83	4.59	6.42	8.28	9.94	11.44	12.79	13.59	13.94	13.85	13.38	12.72	11.85	11.01	10.14
1250	0	0	0	0.54	2.35	4.22	5.89	7.41	8.82	9.70	10.13	10.12	9.71	9.10	8.28	7.47	6.62
1600	0	0	0	0	0.34	2.19	3.85	5.40	6.84	7.77	8.28	8.35	8.01	7.46	6.68	5.90	5.09
2000	0	0	0	0	2.00	3.80	5.46	7.00	8.46	9.43	10.00	10.13	9.86	9.35	8.62	7.87	7.08
2500	0	0	0	0	1.27	3.01	4.63	6.16	7.63	8.64	9.25	9.44	9.24	8.78	8.09	7.37	6.60
3150	0	0	0	0	0	0	0.89	2.39	3.86	4.89	5.55	5.81	5.67	5.26	4.61	3.92	3.16
4000	0	0	0	0	0	0	0	0	0.91	1.96	2.67	2.99	2.91	2.54	1.92	1.23	0.48

TABLE 3 - EXCESS SOUND ATTENUATION VALUES - THEORETICAL

C. Flow Resistivity of 100 CGS Rayls - Attenuation Relative to Hard Surface

THEORETICAL ESA-ABS. R 100

FREQ	DISTANCE IN FEET																
HZ	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	6300	8000	10000
50	0.49	0.50	0.53	0.57	0.62	0.70	0.79	0.92	1.11	1.35	1.65	2.06	2.61	3.29	4.26	5.39	6.82
63	0.84	0.89	0.96	1.05	1.18	1.34	1.55	1.82	2.21	2.66	3.25	4.04	5.09	6.34	8.11	10.11	12.55
80	1.45	1.57	1.73	1.93	2.18	2.53	2.95	3.49	4.25	5.14	6.26	7.73	9.65	11.87	14.82	17.86	21.01
100	2.37	2.61	2.93	3.31	3.80	4.46	5.23	6.21	7.59	9.16	11.10	13.55	16.55	19.64	23.02	25.70	27.92
125	3.84	4.30	4.90	5.60	6.51	7.69	9.07	10.78	13.12	15.66	18.57	21.80	24.95	27.46	29.69	31.26	32.33
160	6.50	7.39	8.54	9.87	11.56	13.71	16.12	18.91	22.30	25.32	27.97	30.19	31.96	33.09	33.49	33.69	33.30
200	10.31	11.87	13.85	16.07	18.77	21.93	24.99	27.84	30.45	32.26	33.57	34.34	34.53	34.24	33.59	32.82	31.96
250	15.83	18.30	21.21	24.13	27.04	29.66	31.63	33.18	34.35	34.86	34.87	34.48	33.78	32.98	32.01	31.08	30.14
315	21.15	23.49	25.75	27.67	29.49	31.17	32.48	33.42	33.93	33.90	33.50	32.83	31.97	31.09	30.07	29.12	28.17
400	19.87	21.62	23.45	25.16	26.89	28.56	29.91	30.93	31.56	31.64	31.32	30.71	29.88	29.02	28.01	27.07	26.12
500	16.44	18.18	20.03	21.77	23.55	25.30	26.78	28.00	28.89	29.21	29.09	28.61	27.87	27.05	26.07	25.15	24.21
630	13.08	14.84	16.70	18.46	20.27	22.09	23.66	25.02	26.13	26.67	26.75	26.42	25.78	25.02	24.07	23.17	22.26
800	10.05	11.80	13.66	15.42	17.25	19.10	20.73	22.18	23.44	24.14	24.38	24.18	23.64	22.93	22.02	21.15	20.26
1000	7.57	9.28	11.12	12.87	14.70	16.57	18.22	19.72	21.07	21.88	22.22	22.13	21.66	21.00	20.14	19.29	18.42
1250	5.39	7.02	8.81	10.54	12.36	14.22	15.89	17.42	18.82	19.70	20.13	20.12	19.72	19.10	18.28	17.47	16.63
1600	3.32	4.79	6.48	8.16	9.94	11.78	13.45	14.99	16.43	17.37	17.88	17.94	17.61	17.06	16.28	15.50	14.69
2000	1.83	3.04	4.57	6.16	7.88	9.69	11.34	12.88	14.34	15.32	15.88	16.01	15.74	15.24	14.50	13.76	12.97
2500	0.83	1.61	2.88	4.32	5.94	7.69	9.31	10.83	12.30	13.31	13.92	14.12	13.91	13.45	12.76	12.04	11.28
3150	0.66	0.64	1.44	2.62	4.08	5.71	7.27	8.77	10.23	11.27	11.93	12.19	12.08	11.64	10.99	10.30	9.53
4000	0	0.56	0.48	1.20	2.36	3.82	5.27	6.71	8.18	9.21	9.92	10.23	10.15	9.79	9.16	8.48	7.73

3. ANALYTIC RESULTS

A-level differences for the three sets of ESA values based on the Dayton field measurements and also A-level differences using the current NOISEMAP algorithms* are shown for each aircraft spectrum set in Figs. 9 through 17. These show clearly the significant differences in ESA values for the three wind conditions varying from moderate upwind to moderate downwind conditions. Note that the ESA values for the NOISEMAP algorithm, shown in the figures, approximate the values for the field data for downwind conditions at distances of about 1000 feet or greater. Without the 5dB added to the values of Table 2, the NOISEMAP values fall well below the downwind field curve.

Figures 18, 19 and 20 show the average excess attenuation as well as the maximum and minimum values for the nine spectra for each of the three wind component conditions. The average values together with the standard deviation for these three conditions and for the NOISEMAP calculations are tabulated in Table 4. For the three wind component conditions the standard deviations range from approximately 0.6 to 4 dB, typically averaging 2 dB or less with the values generally tending to increase with distance.

* The NOISEMAP ESA values in Table 2 (with +5 dB) were used to obtain the NOISEMAP, A-level difference curves in Figures 9 through 17.

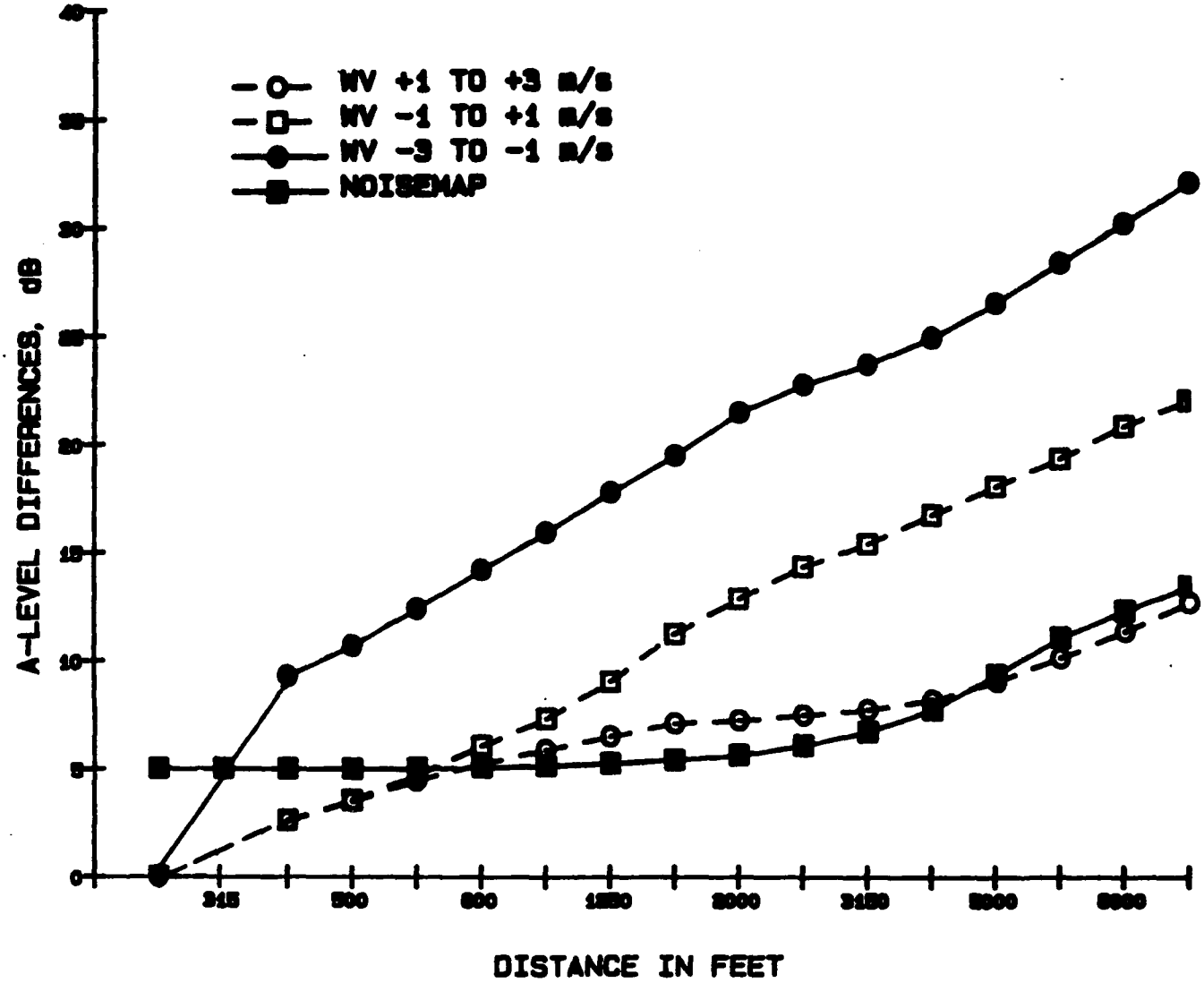


FIGURE 9. A-LEVEL EXCESS ATTENUATION WITH DISTANCE - C-135 A, TAKEOFF (WET) POWER

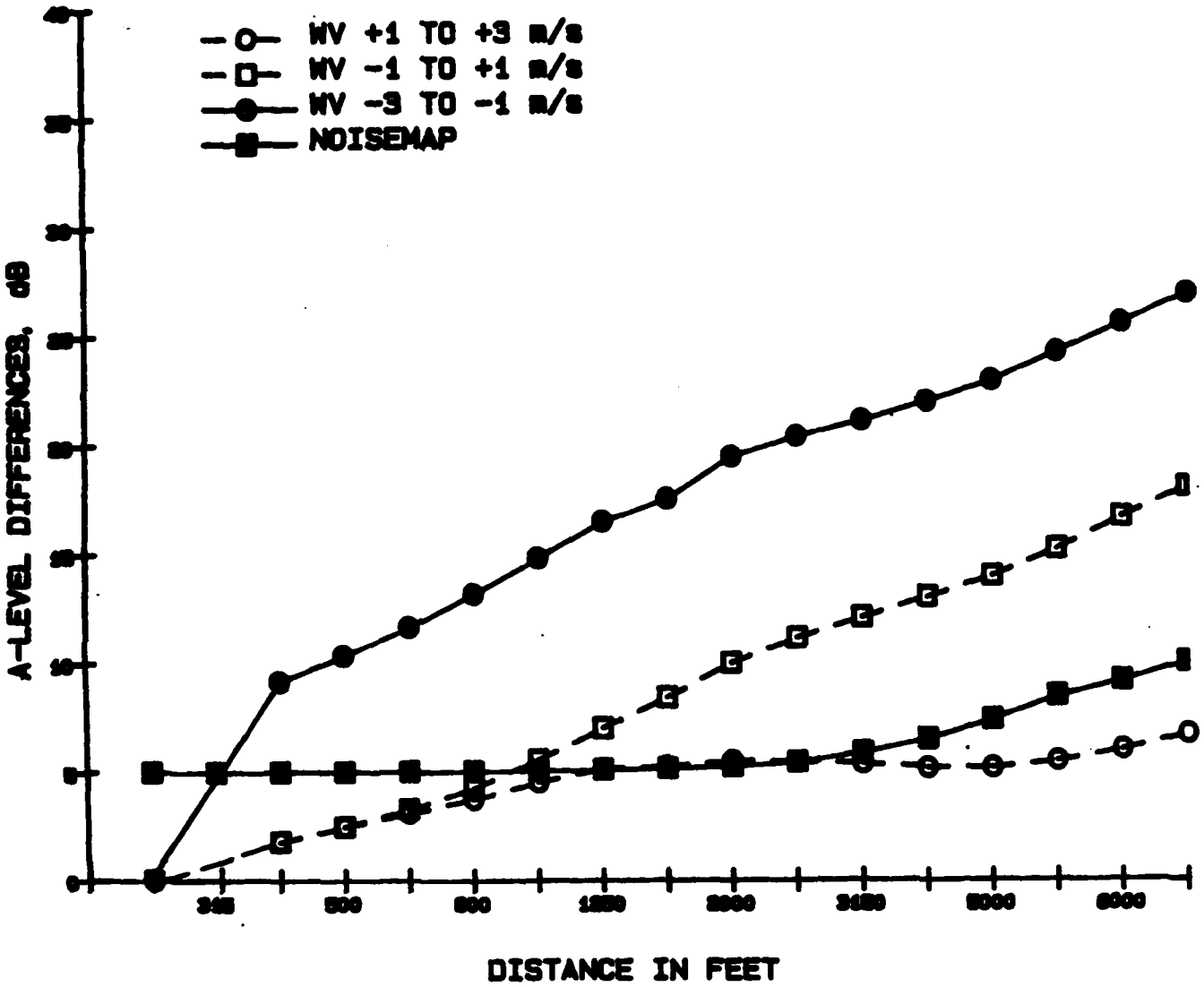


FIGURE 10. A-LEVEL EXCESS ATTENUATION WITH DISTANCE - C-135A, APPROACH POWER

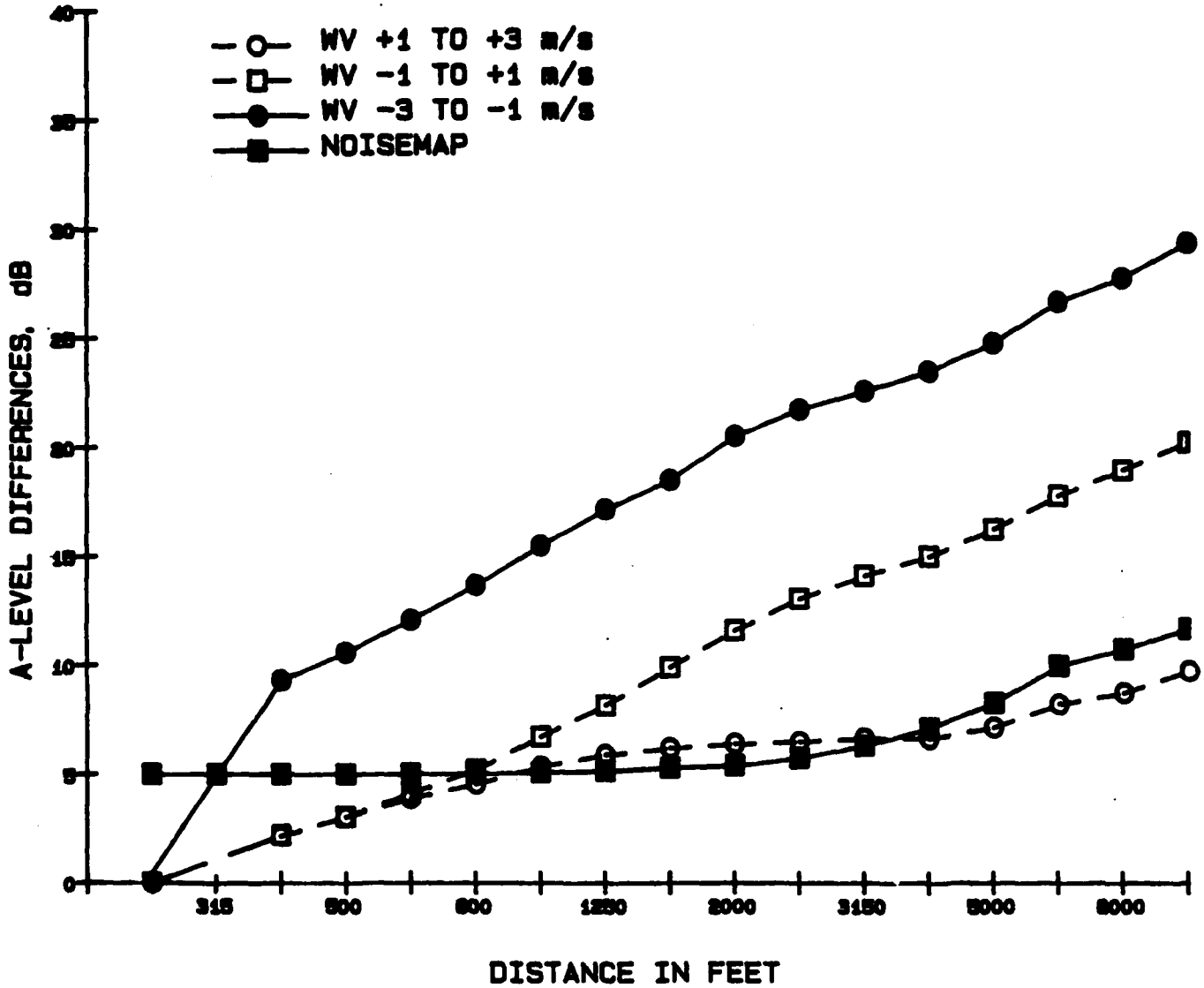


FIGURE 11. A-LEVEL EXCESS ATTENUATION WITH DISTANCE - C-9, TAKEOFF-POWER

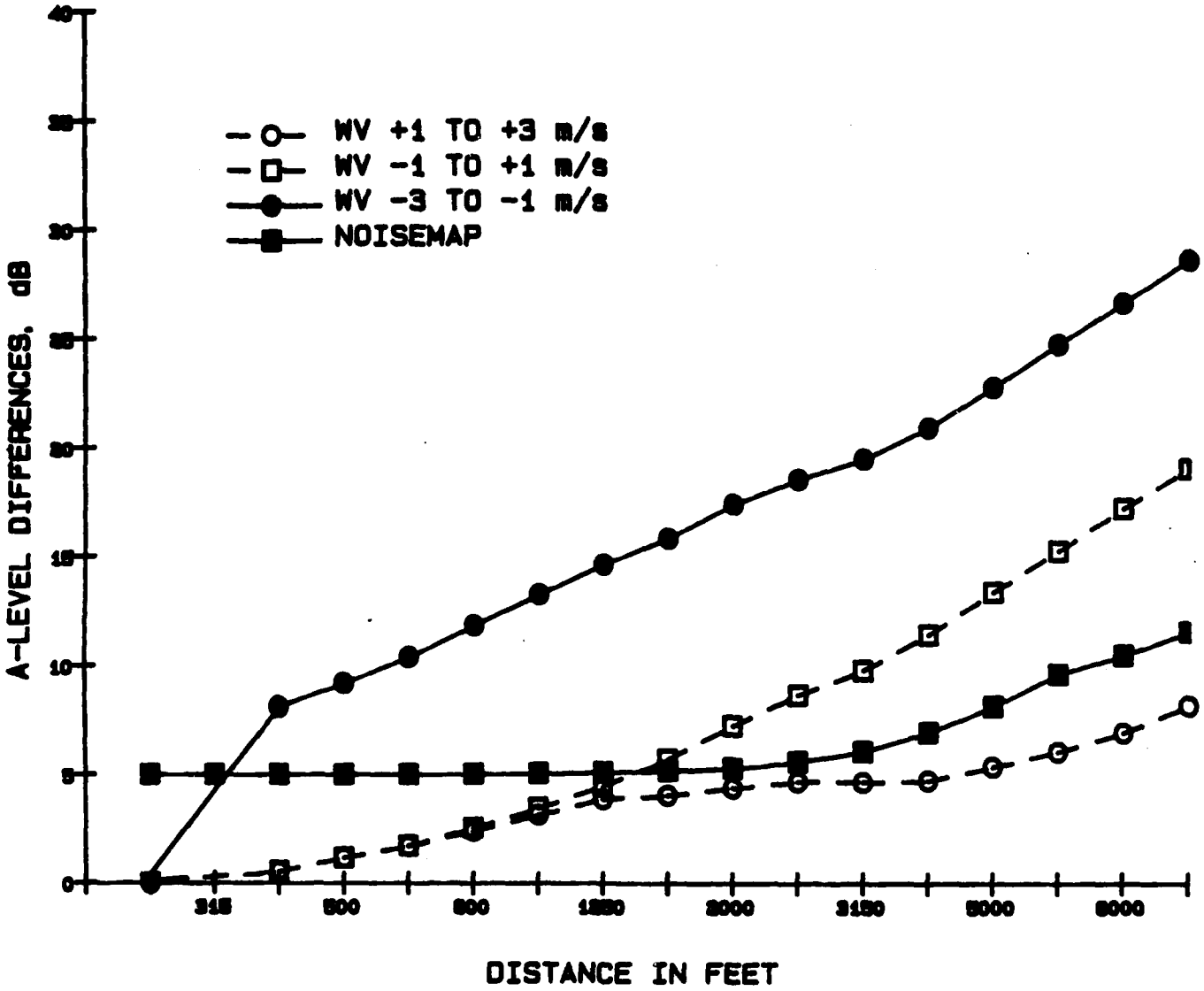


FIGURE 12. A-LEVEL EXCESS ATTENUATION WITH DISTANCE - C-9, APPROACH POWER

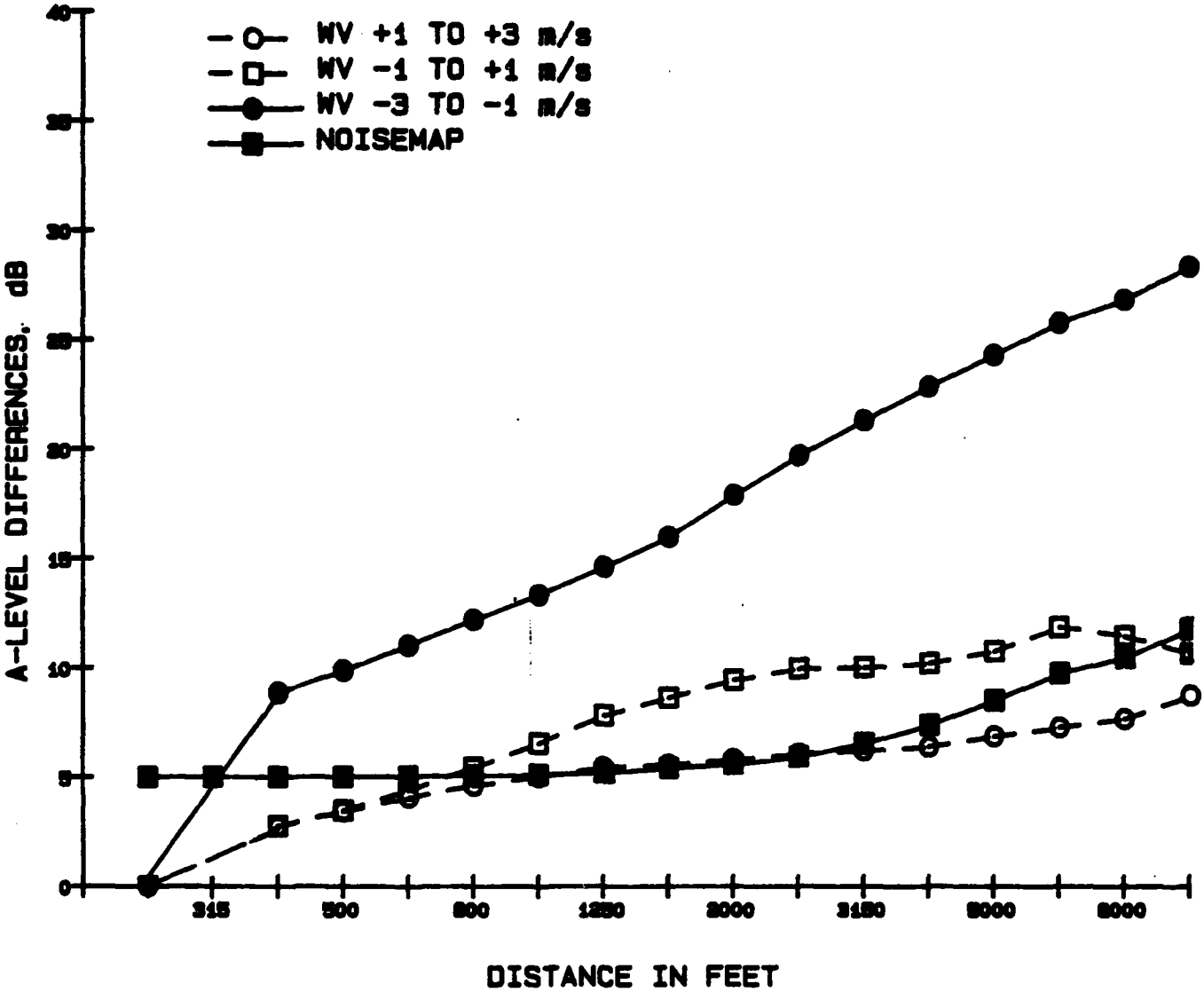


FIGURE 13. A-LEVEL EXCESS ATTENUATION WITH DISTANCE - C-130 H, TAKEOFF POWER

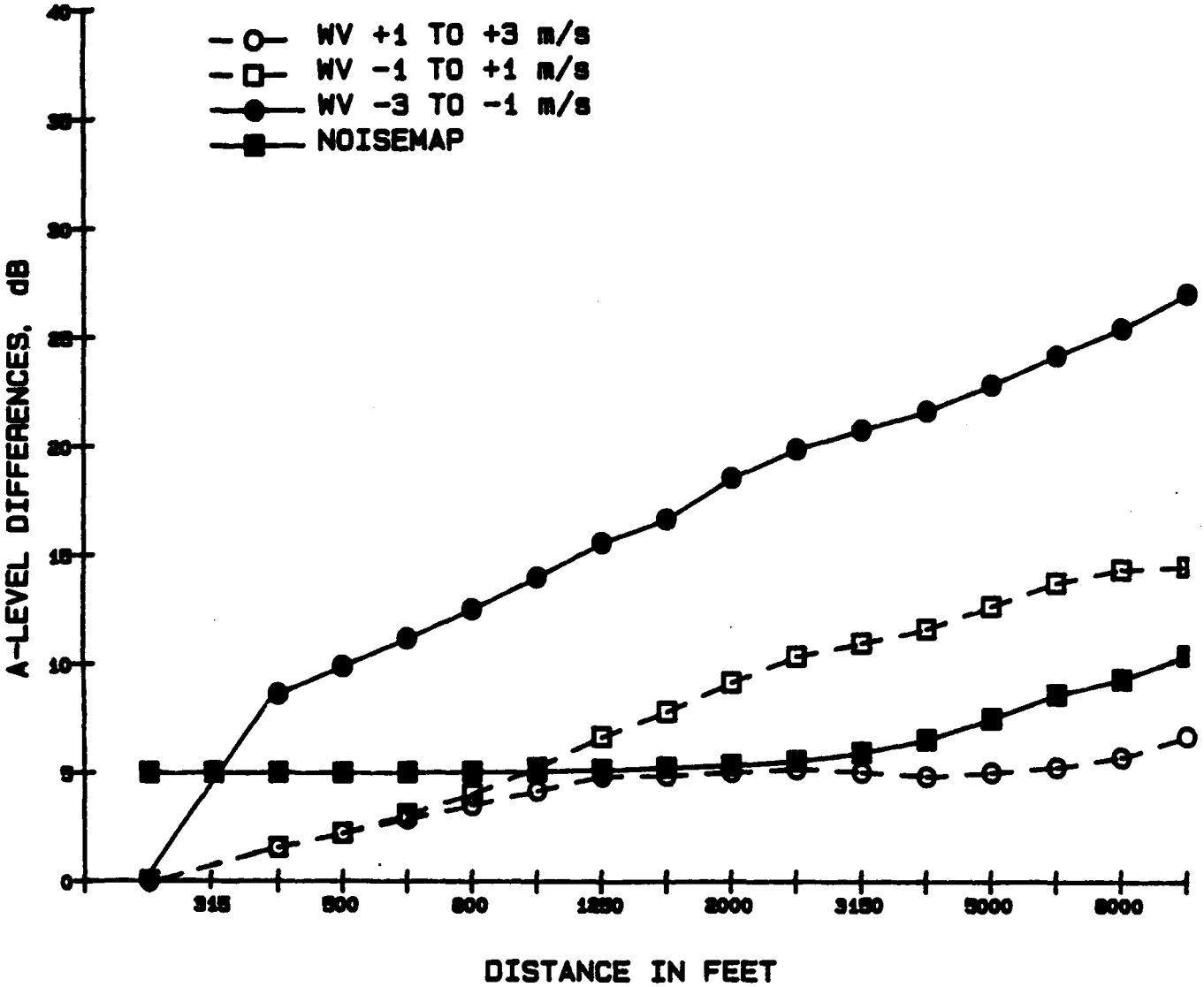


FIGURE 14. A-LEVEL EXCESS ATTENUATION WITH DISTANCE - C-130 H, APPROACH POWER

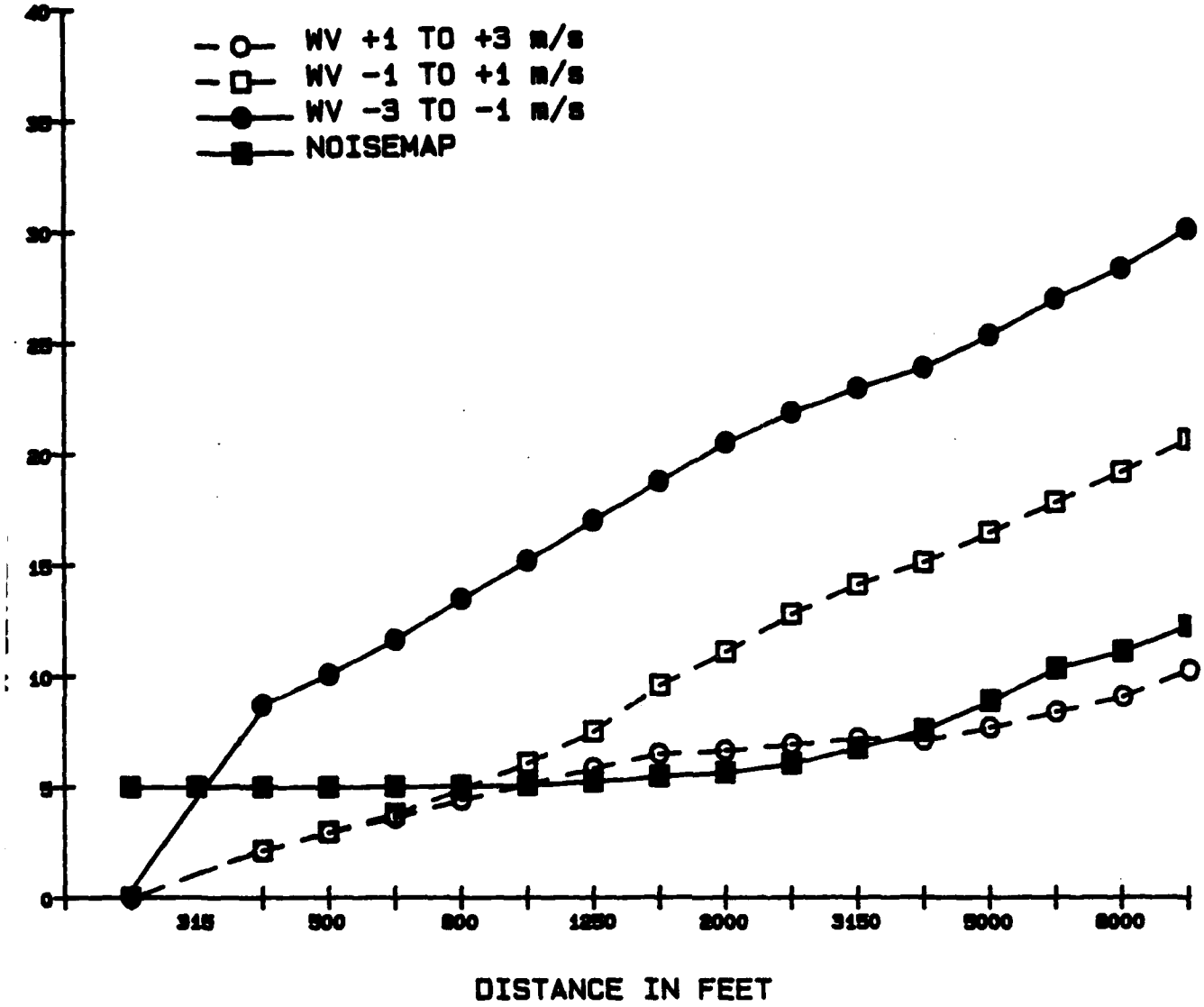


FIGURE 15. A-LEVEL EXCESS ATTENUATION WITH DISTANCE - F-16, TAKEOFF (AFTERBURNER) POWER

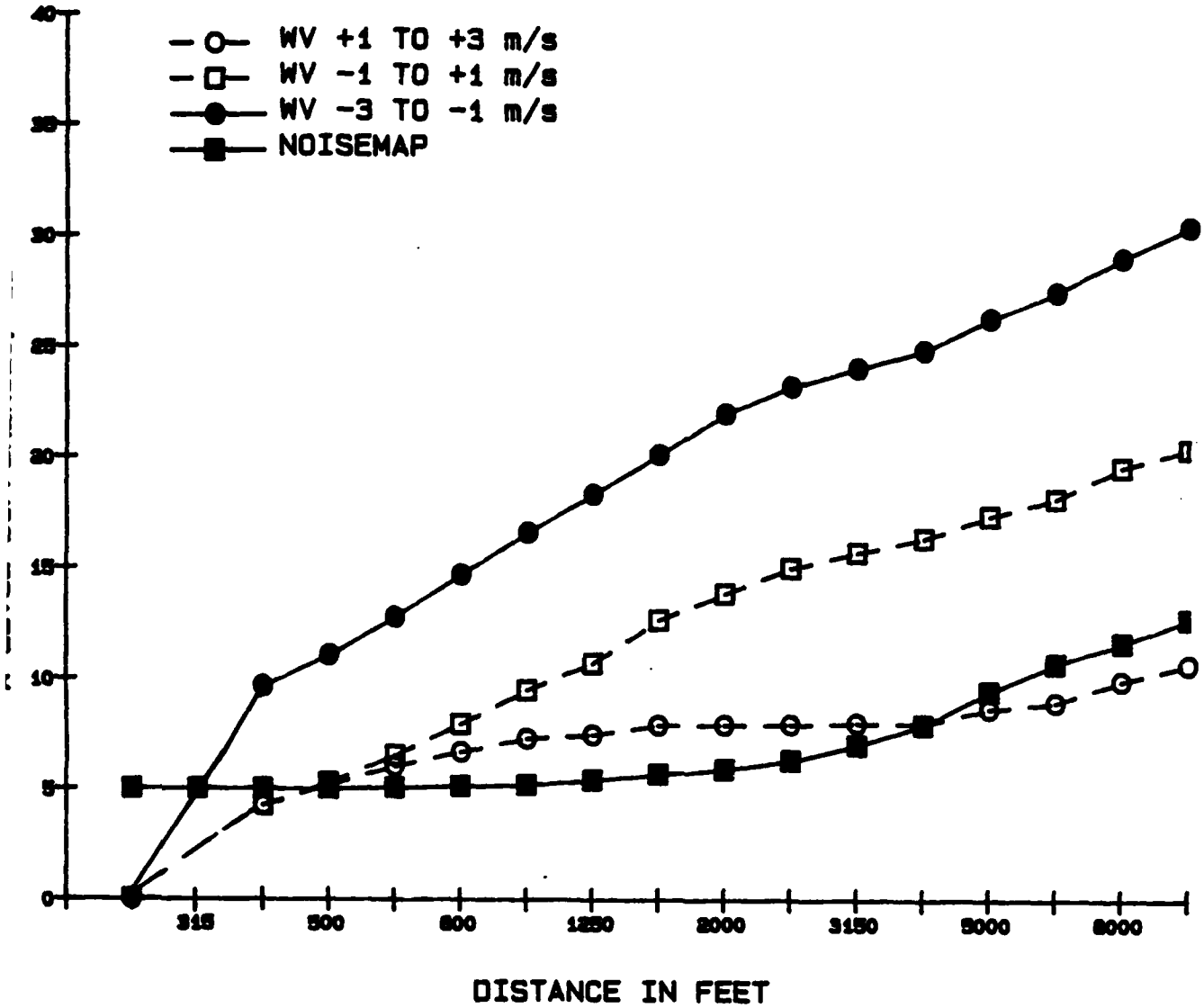


FIGURE 16. A-LEVEL EXCESS ATTENUATION WITH DISTANCE - F-16, APPROACH POWER

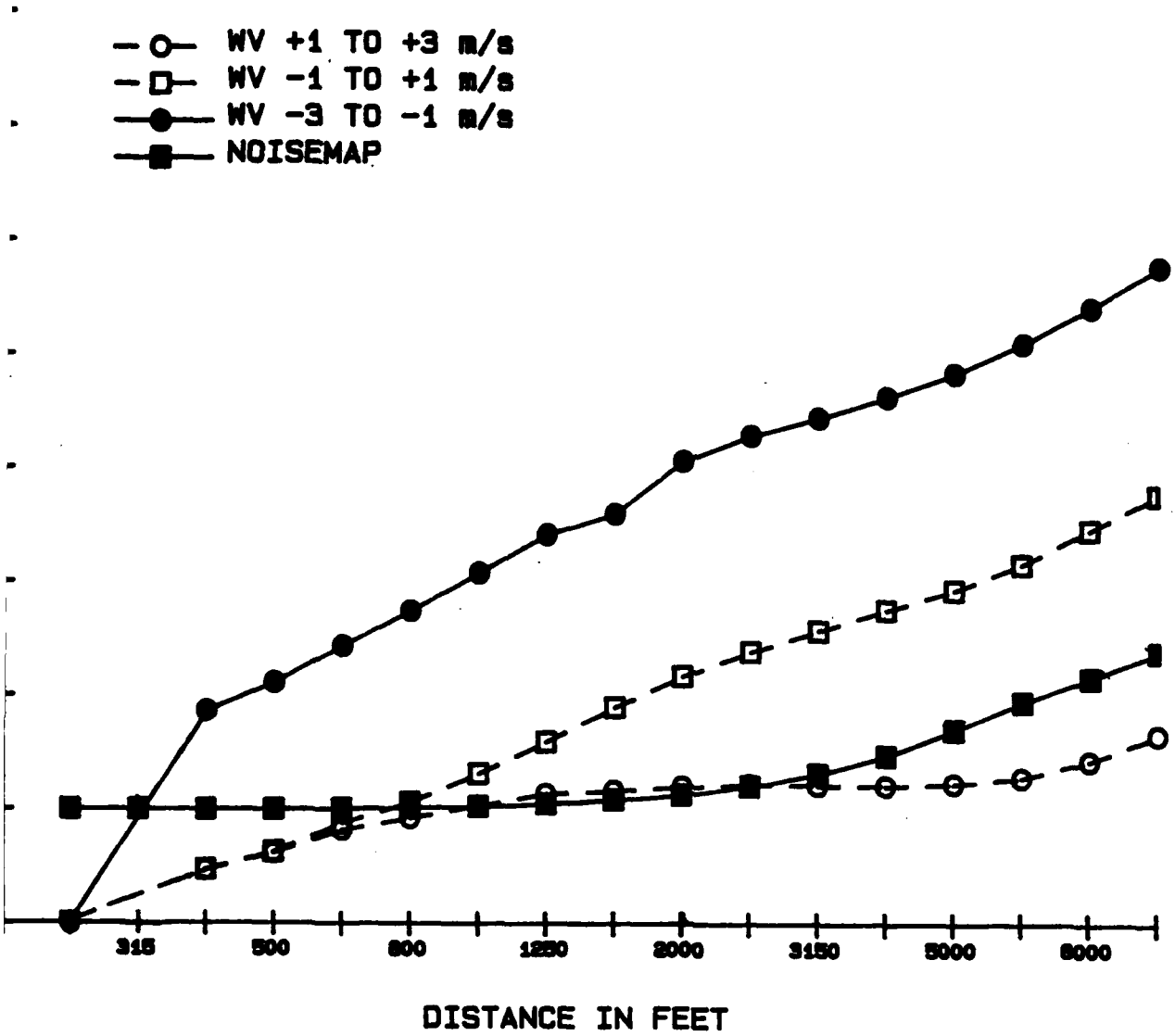


FIGURE 17. A-LEVEL EXCESS ATTENUATION WITH DISTANCE - CHALLENGER 600, TAKEOFF POWER

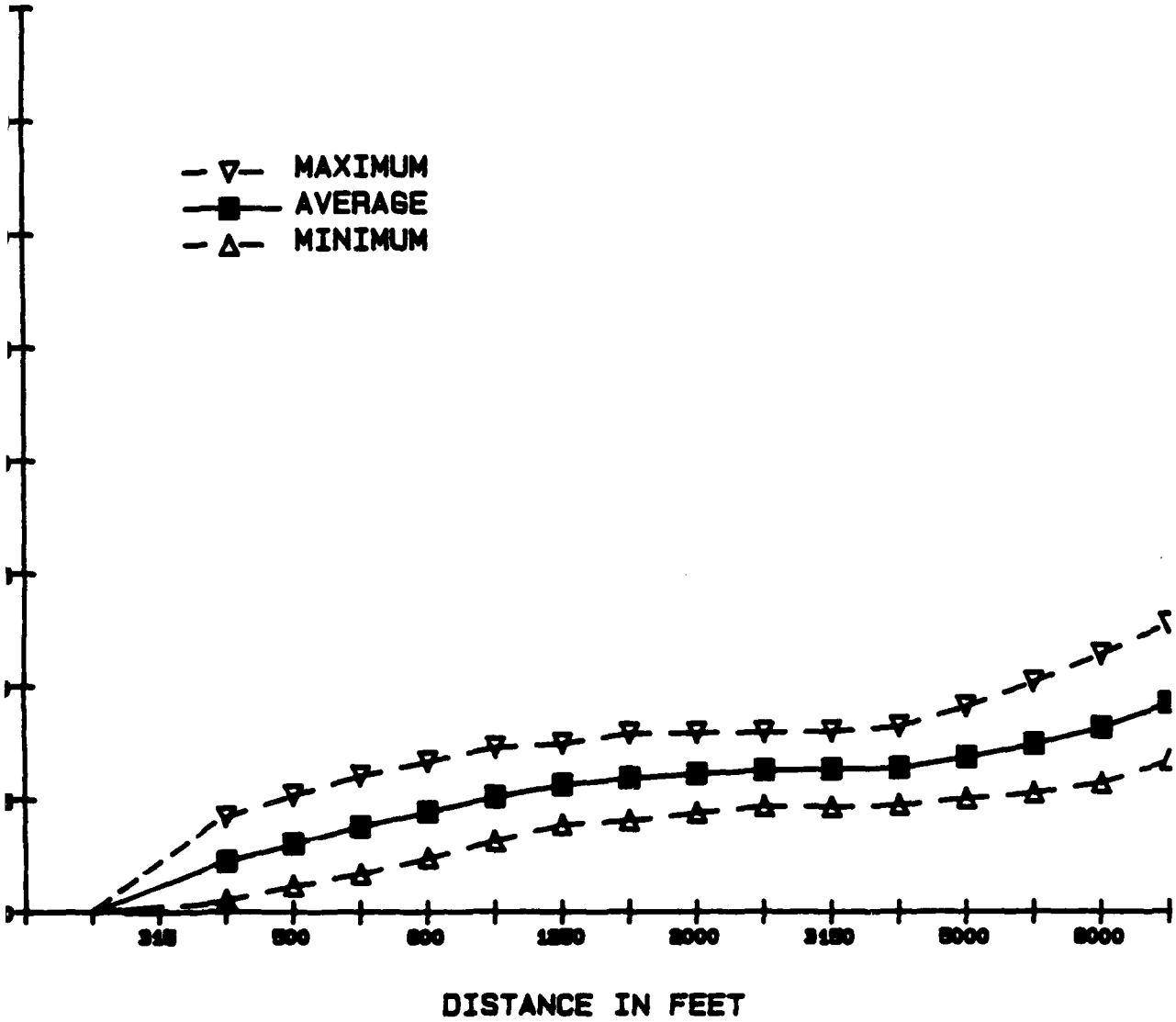
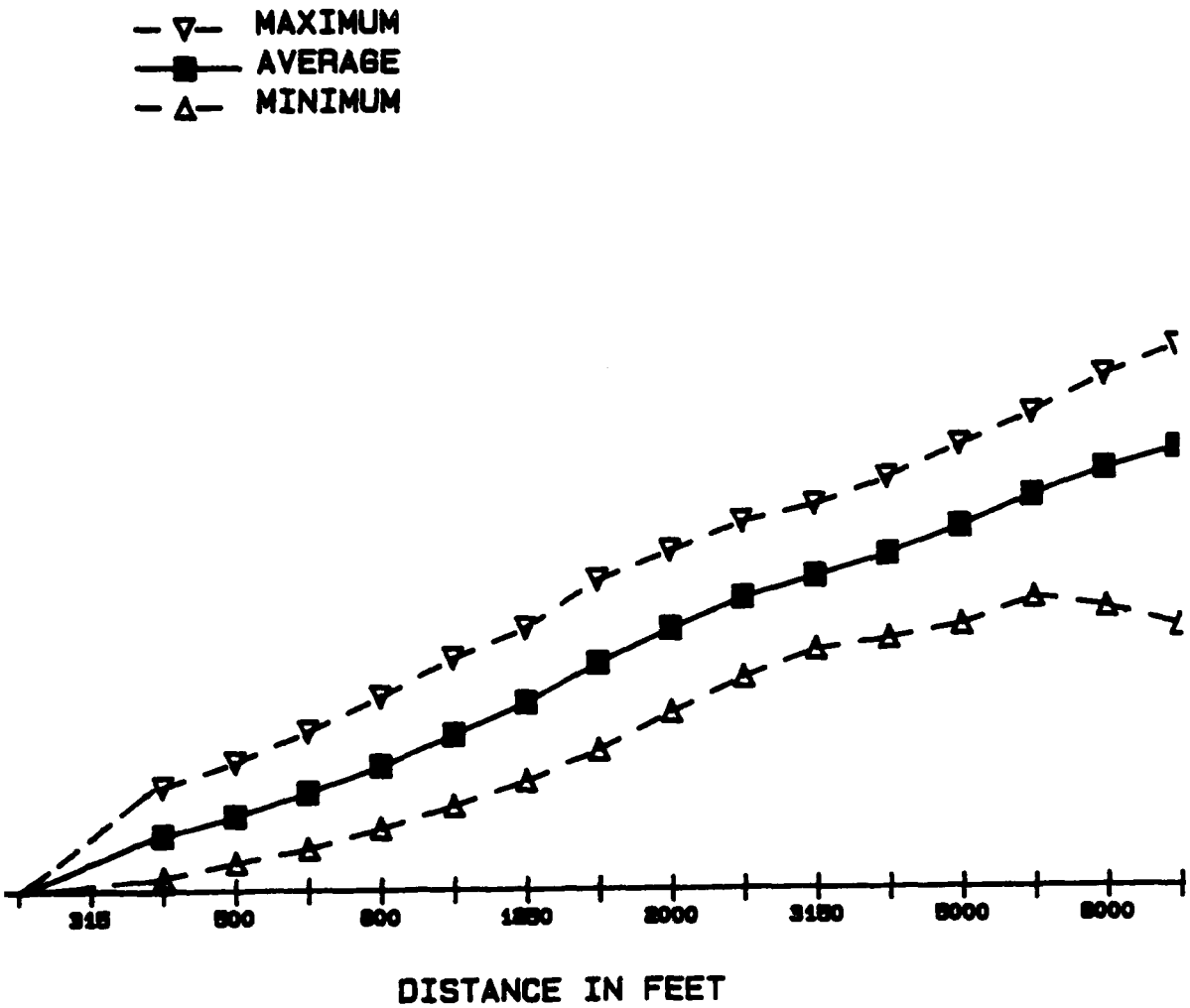


FIGURE 18. AVERAGE A-LEVEL EXCESS ATTENUATION FOR NINE AIRCRAFT SPECTRA - WIND COMPONENT OF +1 TO +3 METERS/SECOND



E 19. AVERAGE A-LEVEL EXCESS ATTENUATION FOR NINE AIRCRAFT SPECTRA - WIND COMPONENT OF -1 TO +1 METERS/SECOND

With regard to NOISEMAP, there are two questions that become important: (a) How well do the conditions under which the Dayton measurements were obtained represent "typical" airport conditions? and (b) What wind conditions (upwind, downwind, no-wind) should be selected for NOISEMAP applications?

The current NOISEMAP algorithms reflect a conscious choice to utilize ESA values that are based on downwind, rather than no wind or upwind conditions. This conservative approach differs from the SAE selection of a curve based on essentially no wind conditions. This downwind choice is based primarily on the consideration that:

(1) jet takeoff noise is the major noise source at most airports
(2) for jet aircraft at high thrusts, more noise is radiated to the rear quadrant than to the forward quadrant

With most takeoffs occurring into the wind, factors (1) and (2) suggest that the wind component for the maximum takeoff levels will average to have a net downwind value.

On this basis, ESA curves based on the moderate downwind Dayton measurements appear most suitable for calculating over-ground noise levels. One factor which may limit the applicability of curves derived from the Dayton measurements to the NOISEMAP prediction program is that many airport applications involve propagation over non-level, non-uniform terrain, frequently with obstacles that reduce or block direct line-of-sight propagation. The extent to which the ESA values derived from Dayton field measurements hold for such conditions is unknown.

Despite this limitation, which can best be resolved by additional field work, it is believed that the Dayton measurements represent a more extensive and more detailed data base upon which to develop ESA curves than the data base from which the existing NOISEMAP algorithms were derived (ref 8).

5. RECOMMENDATIONS FOR NOISEMAP

This study shows that sets of ESA values derived from the Dayton field measurements predict ESA differences in terms of A-levels that are reasonable and are in accord with expectation (i.e., large differences with wind conditions). Comparison of these curves with the SAE algorithms show differences that are explainable and rational. Comparisons with the NOISEMAP curves show differences that are not fully explainable without better information about the propagation effects when line of sight propagation does not exist.

Comparisons of A-levels based upon the Dayton measurements with theoretical models (for low wind conditions) show reasonable agreement. This provides considerable experimental support of theoretical analysis in other propagation applications. It also supports the use of the curves derived from the field data for propagation predictions over nearly level surfaces.*

With respect to NOISEMAP application, a quote from Reference 2 is meaningful:

Contours generated by NOISEMAP are usually intended to depict a noise environment in the vicinity of an airbase based upon 'typical' or 'average' conditions existing over a period of time, usually average annual conditions. To this end, it is desirable to use air absorption and excess attenuation values as a representative of average conditions at the particular airbase. Where it is difficult to determine average conditions over a year, or where there are large seasonal differences, the intent is to select conditions that are representative during the time of the year that people are likely to be most sensitive to noise (summer rather than winter conditions, for example). ...Considering prevailing wind conditions and the variation in terrain that exist around any airbase, it is clear that average excess attenuation values, when they are accurately determined, will vary from point to point, and will vary with respect to the source location. It will probably never be practicable, or desirable, to determine sets of average excess attenuation values for each different grid location in computing contours.

*It is believed that the ESA values derived from the Dayton measurements (Table 1) provide reasonably accurate values for estimating excess attenuation for zero, and moderate positive and negative wind component values for propagation over near-level grassy terrain.

6. With regard to the excess attenuation values based upon the theoretical model, the ESA values for the two assumptions as to the ground flow resistance show very little difference, reflecting the relatively very small difference in the shape of the ESA values at any given distance. However, the choice of reference conditions can result in sizable differences (compare Figs. 22 and 23 with 24).

   Although the absolute magnitude of the ESA differences with the theoretical model compared to the zero wind Dayton curves are not far different, there are differences in the rate of change with distance, as noted clearly in Fig. 25. However, the differences do not appear large enough to destroy the great usefulness of the theoretical model for further calculations.*

*The use of a theoretical model in predicting the change in excess attenuation as a function of elevation angle is discussed in Ref.7.

additional experimental measurements -- or more detailed theoretical analysis.

A significant portion of the observed Dayton attenuation, at least under no wind conditions, is similar to what is expected theoretically due to interference from a surface of finite impedance. Thus, the blockage of line-of-sight propagation, by disrupting reflection effects, may result in increased noise levels (lower ESA values) compared to levels without the blockage.

5. The SAE curve is displaced by the order of 2 to 3 dB above the zero wind component Dayton curve out to a distance of approximately 3000 feet. The curves are near parallel for shorter distances, a situation that is understandable since both curves are based upon field measurements over grassy surface under low-temperature gradient and low-wind component conditions.*

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* The SAE curve has been derived from octave band ESA values based upon the measurements under winter conditions at Radlett, England (Ref. 6). In a manner similar to that used in this study, the octave band ESA corrections were applied to a variety of aircraft spectra and a mean curve was developed. The Radlett field measurements extended only to 3600 feet, which accounts for the leveling off of the SAE curve at distances above about 3000 feet as shown in Fig. 21. The greater attenuation at shorter distances given by the SAE curve may be accounted for, in large part, from the fact that the reference measuring positions in the Radlett measurements were much closer to the source that the 250-foot distance for the Dayton measurements. Hence, the reported attenuation values from the Radlett measurements likely include more of the "total" excess attenuation between the source and distant measurement positions. This does not mean there are problems with the Dayton data since, in the NOISEMAP application of Dayton data, the noise source is always defined by the noise data at 250 feet, the reference microphone locations.

factor also implies that the small changes in the ESA values as a function of frequency at any given distance are likely to have little effect on the resulting A-level ESA difference; i.e. the A-level differences are not sensitive to small changes in ESA values.

4. Two sets of NOISEMAP ESA curves are typically employed in current contour calculations:
    1. Values as given in Table 2 are used to determine noise levels at varying distances for ground runup noise.
    2. Values of Table 2 with a value of 5 dB added are used for predicting flight noise and predicting the transition between over ground propagation and overhead propagation of aircraft flight noise (see ref. 7).

With the 5 dB addition to the values of table 2, the NOISEMAP and Dayton downwind curves yield similar values of attenuation over the distance range of approximately 1000 to 4000 feet with the NOISEMAP values exceeding the downwind data curves at shorter or longer distances. Without the 5 dB added, the NOISEMAP curves fall below the downwind data curves over most of the distance range.

The NOISEMAP curves (without the added 5 dB) are based upon downwind noise propagation measurements at commercial airports in which line-of-site propagation was blocked -- a situation frequently encountered in both military and civil airfield situations.

A key question to be answered is to whether downwind propagation with blockage results in lower or higher noise levels then would be expected for line-of-sight propagation. The differences between the NOISEMAP curve (without the 5 dB adjustment) and downwind data curves cannot be fully explained or understood without

1. Spectrum shape does influence the A-level differences, and the differences in A-levels among aircraft are quite sizable (standard deviations among spectrum of the order of 1 to 2 dB).

2. As expected, there are very sizable differences in the A-level attenuation with wind conditions. For neutral and upwind propagation, the A-level differences show an almost constant rate of increase with the logarithm of distance. For upwind propagation the rate is approximately 4.3 dB per octave (14.3 dB per decade) and with zero wind component the rate of change with distance is nearly the same--3.5 dB per doubling of distance (11.7 dB per decade distance of change). The displacement between the two curves is roughly constant, varying from 7 to 11 dB. The downwind condition obviously shows much lower attenuation and the rate of change with distance is more irregular.

3. The rate of change of A-level differences as a function of distance is a function of both the ESA values and the change in noise spectrum shape due to air absorption. The ESA values are at a maximum at midfrequencies of the order of 200 to 500 Hz; hence, the reduction of levels in this frequency range affects the A-levels increasingly as the higher frequency levels decrease with distance due to air absorption. Thus, even with a constant set of ESA values that did not increase with distance, there would be an increase in the A-level differences with distance because of the loss of high-frequency sound energy. As an example, the maximum attenuation values in any given 1/3 octave band for the upwind propagation increase with distance out to approximately 3000 feet, and do not increase at higher distances. However, the A-level ESA values show a near-uniform rate of increase out to 10,000 feet. This

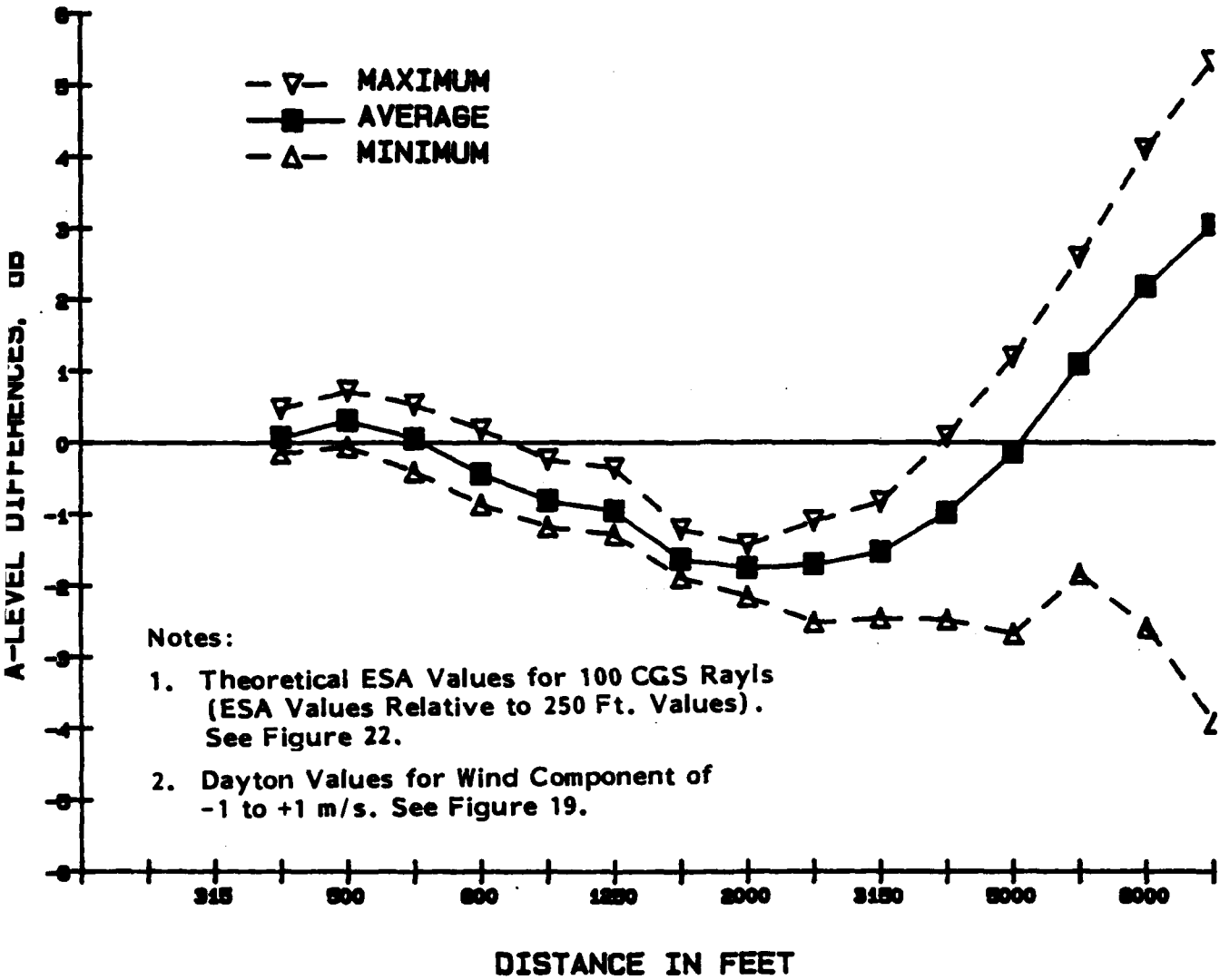

FIGURE 25. AVERAGE DIFFERENCES IN A-LEVEL EXCESS ATTENUATION FOR NINE AIRCRAFT SPECTRA - DAYTON MEASUREMENTS MINUS THEORY

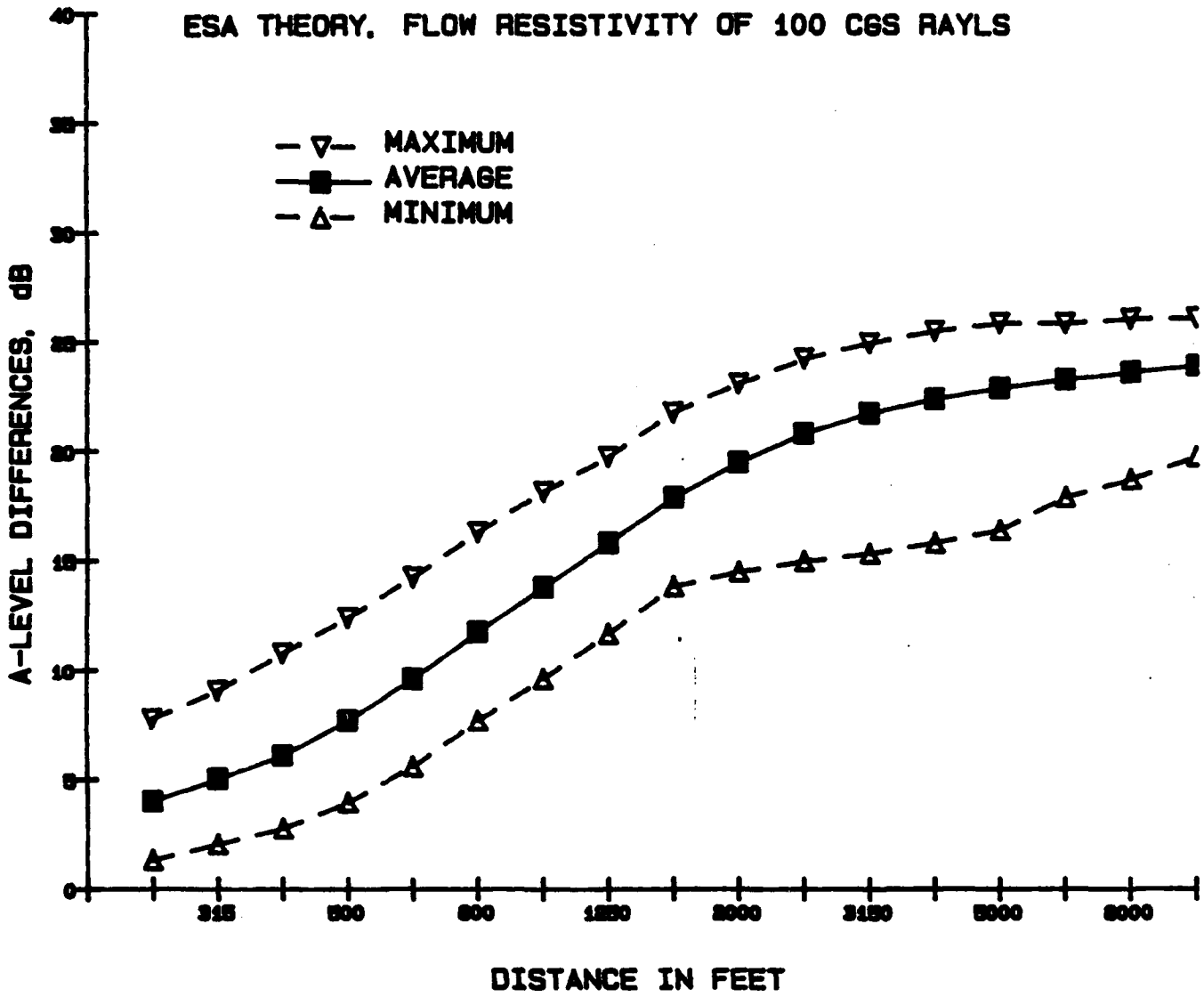

FIGURE 24. AVERAGE A-LEVEL EXCESS ATTENUATION FOR NINE AIRCRAFT SPECTRA - THEORETICAL ESA VALUES RE INFINITELY HARD REFLECTING SURFACE

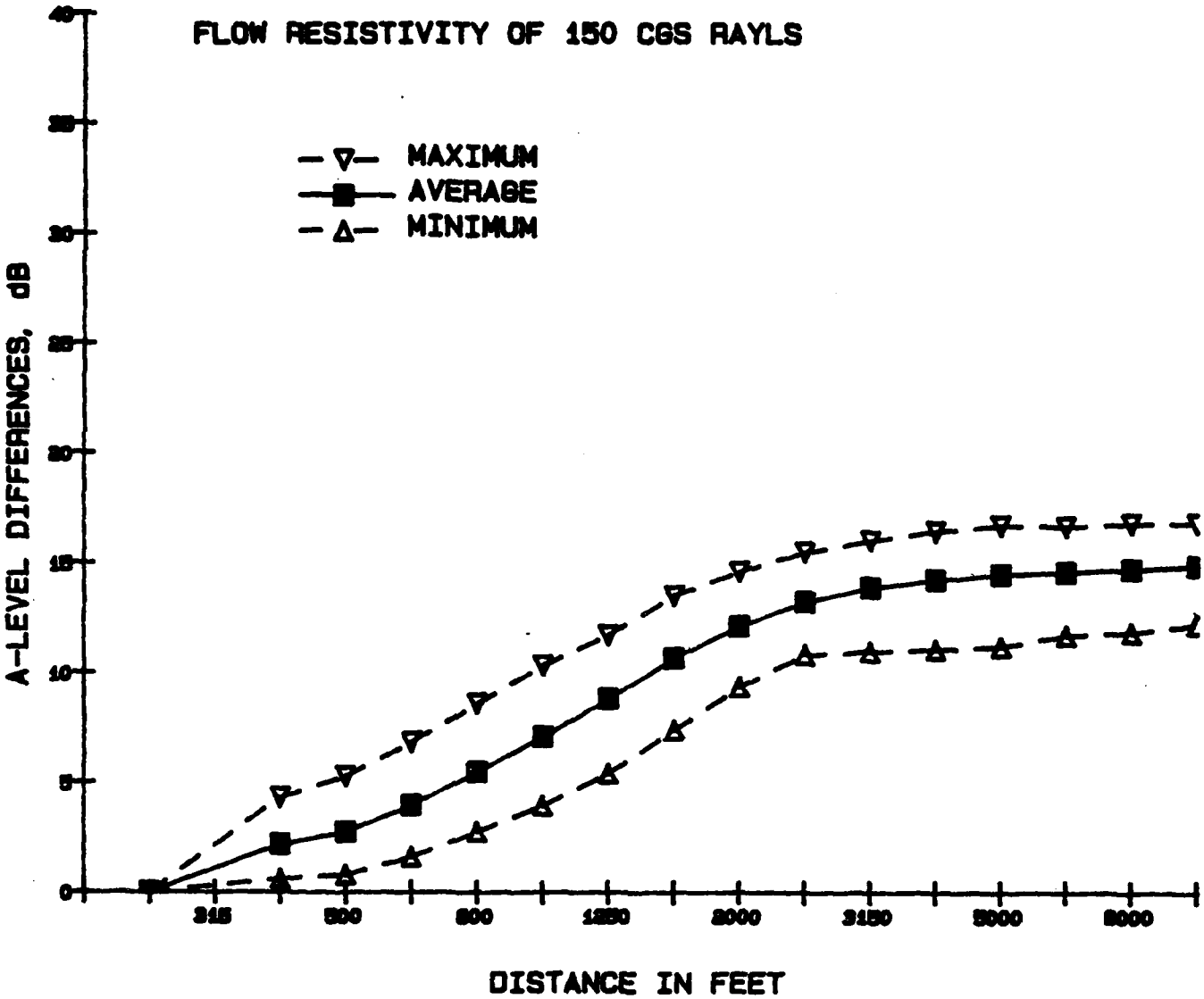

FIGURE 23. AVERAGE A-LEVEL EXCESS ATTENUATION FOR NINE AIRCRAFT SPECTRA - THEORETICAL ESA VALUES RELATIVE TO 250 FEET VALUES

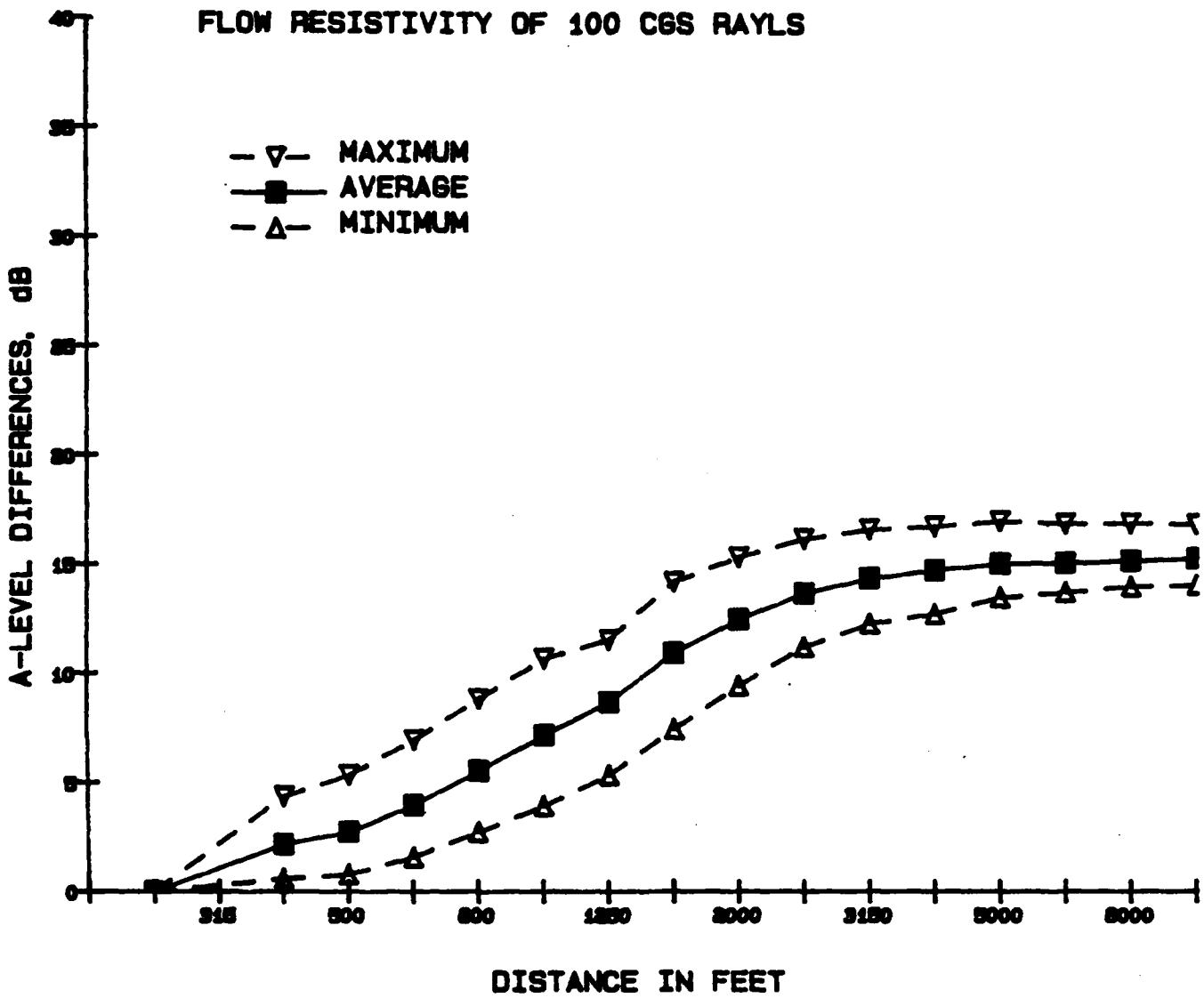

FIGURE 22. AVERAGE A-LEVEL EXCESS ATTENUATION FOR NINE AIRCRAFT SPECTRA - THEORETICAL ESA VALUES RELATIVE TO 250 FT.VALUES

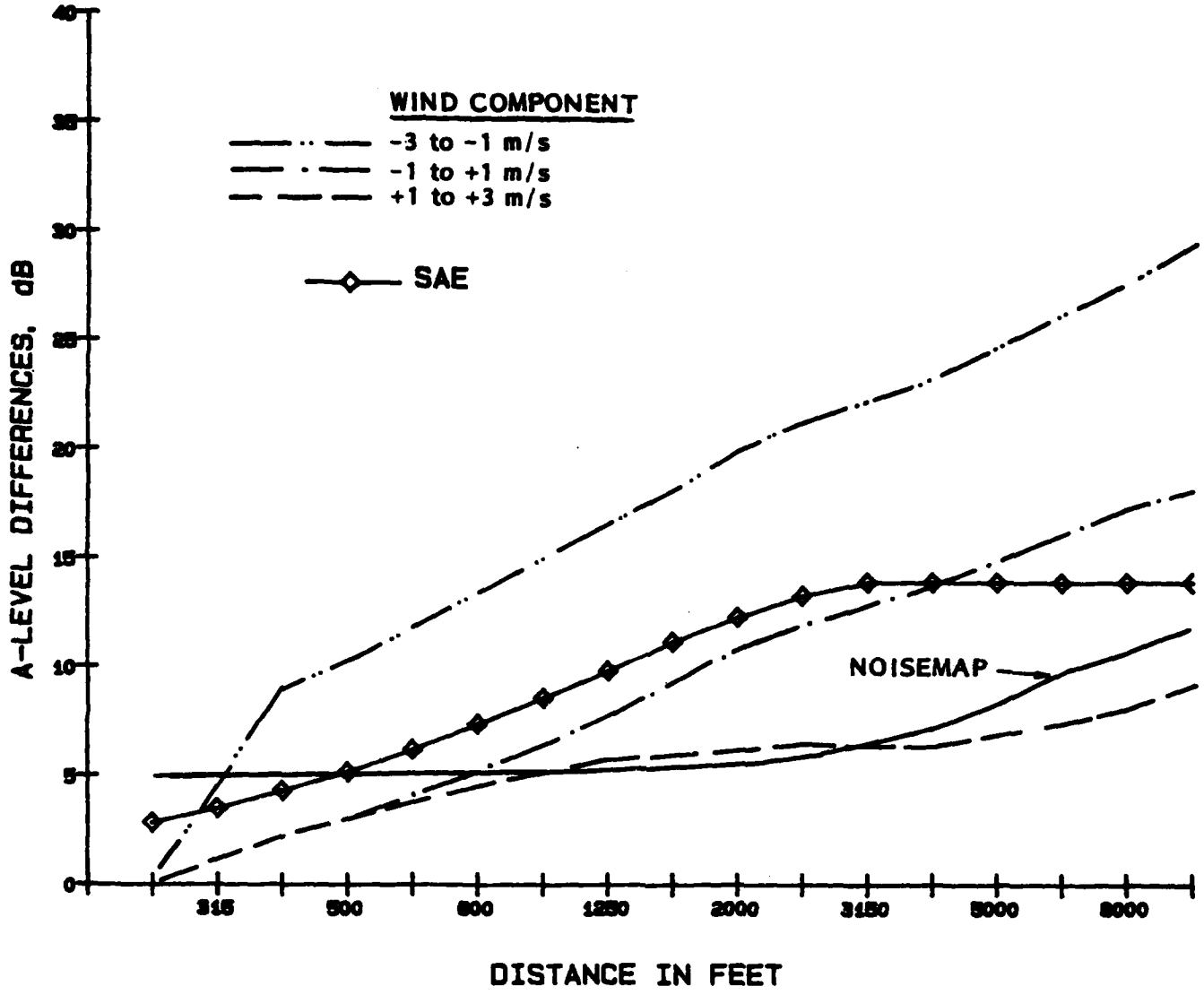

FIGURE 21. COMPARISON OF AVERAGE A-LEVEL EXCESS ATTENUATION FOR NINE AIRCRAFT SPECTRA WITH SAE ATTENUATION CURVE

The average values for the three wind conditions as well as for NOISEMAP, all from Table 4, are plotted in Fig. 21 together with the SAE excess attenuation curve (which, as noted earlier, is aircraft-independent). The SAE curve follows the trend of the curve for the zero wind component conditions out to a distance of approximately 4000 feet, then leveling off at greater distances. Also note that the SAE curve is greater than the average attenuation given by the NOISEMAP algorithms for distances greater than 500 feet.

Turning now to the excess attenuation calculations using the theoretical excess attenuation model, Figs. 22, 23, and 24 show the average excess attenuations for the nine aircraft spectra together with maximum and minimum values for the three theoretical assumptions. All three of the curves represent excess attenuation under neutral temperature gradient and low wind conditions; hence, they can best be compared with the experimental data for low wind component (-1 to +1 m/s) conditions. A comparison of values for the 100 cgs rayls assumptions (Fig. 24) is given in Fig. 25. This shows, on an expanded scale, the average differences in A-level excess attenuation for the nine aircraft spectra comparing the Dayton values minus the theoretical values. You will note that the average differences are less than ±2 dB out to a distance of approximately 6300 feet. However, the A-level differences for the theoretical model show a slightly greater rate of increase with distance out to about 3150 feet and then show a lower rate of increase for greater distances.

4. DISCUSSION

Comparisons of the experimental attenuation values using different aircraft spectra show the following:

TABLE 4. AVERAGE A-LEVEL ESA DIFFERENCES FOR NINE AIRCRAFT SPECTRUM SETS

	WIND COMPONENT							
	-3 TO -1 M/S		-1 TO +1 M/S		+1 TO +3 M/S		NOISEMAP	
DISTANCE FEET	AVE. dB	STD DEV dB	AVE. dB	STD DEV dB	AVE, dB	STD DEV dB	AVE. dB	STD DEV dB
250	0	0	0	0	0	0	5.00	0
315	0	0	0	0	0	0	5.00	0
400	8.98	0.52	2.27	1.17	2.25	1.16	5.00	0
500	10.22	0.62	3.07	1.30	3.03	1.27	5.00	0
630	11.67	0.82	4.02	1.52	3.77	1.38	5.01	0.01
800	13.27	1.01	5.11	1.70	4.44	1.36	5.03	0.03
1000	14.89	1.21	6.36	1.89	5.10	1.32	5.11	0.05
1250	16.49	1.38	7.67	1.96	5.64	1.15	5.22	0.11
1600	17.88	1.58	9.25	2.25	5.93	1.29	5.38	0.18
2000	19.76	1.66	10.64	2.21	6.12	1.20	5.53	0.24
2500	21.01	1.64	11.89	2.24	6.27	1.15	5.86	0.31
3150	21.95	1.60	12.77	2.27	6.32	1.23	6.42	0.42
4000	23.04	1.47	13.65	2.41	6.36	1.32	7.22	0.53
5000	24.47	1.48	14.76	2.58	6.83	1.54	8.43	0.76
6300	26.04	1.57	16.01	2.61	7.42	1.78	9.80	0.93
8000	27.51	1.72	17.08	3.23	8.15	2.01	10.68	1.10
10000	29.17	1.82	17.92	3.97	9.21	2.12	11.74	1.18

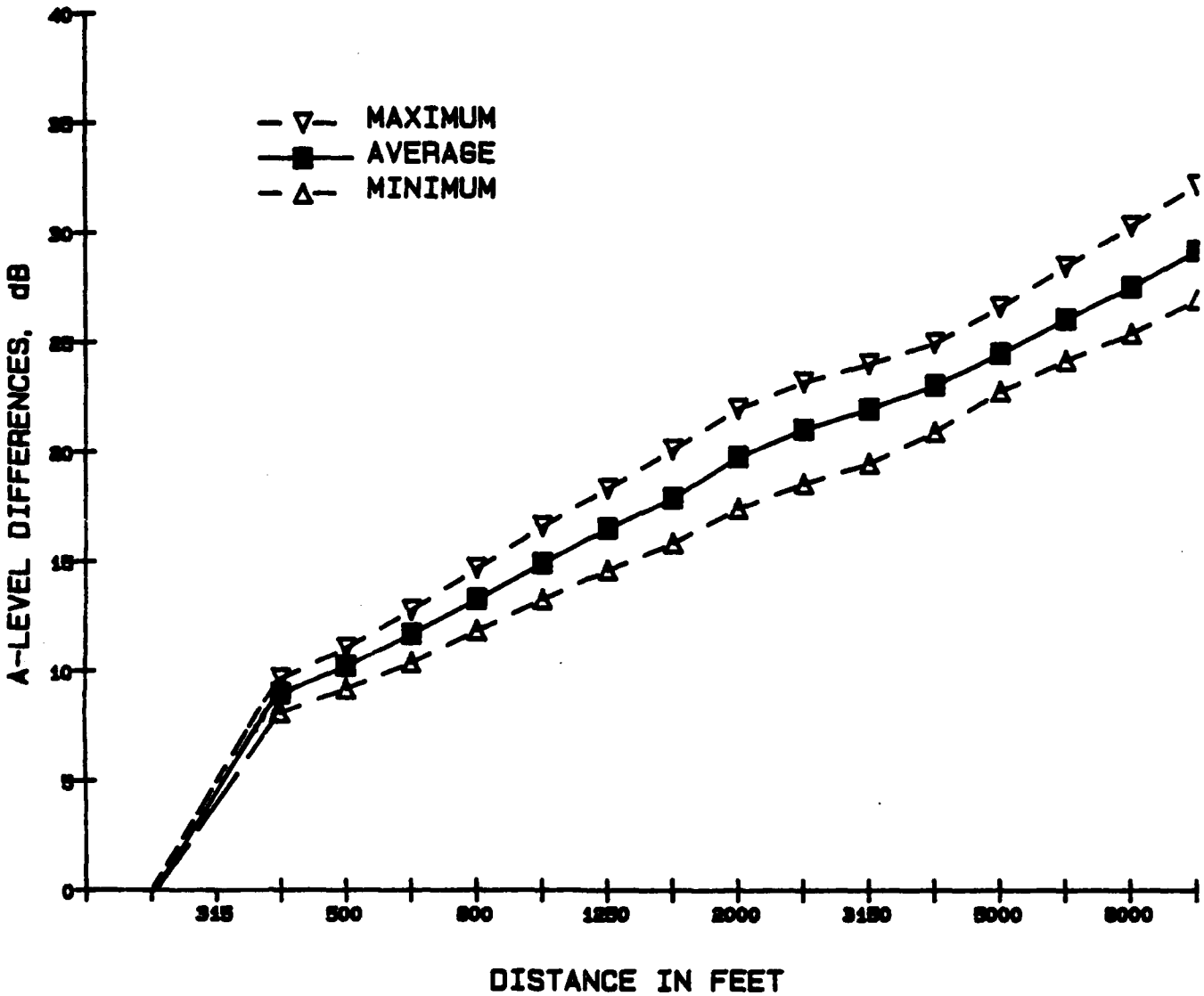

FIGURE 20. AVERAGE A-LEVEL EXCESS ATTENUATION FOR NINE AIRCRAFT SPECTRA - WIND COMPONENT OF -3 TO -1 METERS/SECOND

Thus, it is recommended that ESA curves based on the moderate downwind Dayton data (win component range of +1 to +3 meters/second, Table 2, page 15) replace the current NOISEMAP ESA algorithms. It is further recommended that a single set of curves be used for both flight and ground noise.

The typical effect of implementing of these recommendations can be estimated from Figure 21 (and Figures 9 through 17).

(a) For ground runup noise, the Dayton downwind curves will predict lower levels (of the order of 0 to 4 dB out to 10,000 ft)

(b) For flight noise, the Dayton downwind curves will predict higher levels out to approximately 1000 ft distance, nearly similar levels over the range from 1000 to 4000 ft, and slightly lower levels at distances beyond 4000 ft.

(c) Compared to the SAE curve, the Dayton downwind curves will generally predict consistently higher levels of the order of 2 to 6 dB.

To obtain better information on over-ground propagation when terrain or buildings block line-of-sight propagation, it is strongly recommended that additional ESA field data, similar to the Dayton measurements, be acquired over more irregular terrain, as discussed in reference 2.

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