

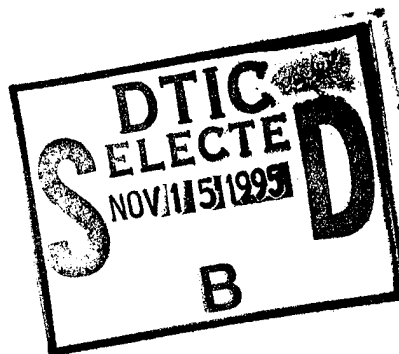
AFAMRL-TR-85-018



**LATERAL ATTENUATION OF
AIRCRAFT FLIGHT NOISE**

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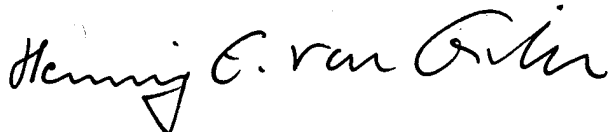
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FOR THE COMMANDER



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

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| <p>This report reviews models for calculating the lateral attenuation of aircraft flight noise, in particular, the change in attenuation for different elevation angles varying from aircraft directly overhead (90° elevation angle) to a zero elevation angle. Sets of noise spectrum-dependent lateral attenuation values derived from theory and from experimental (AMRL) flight measurements were applied to sets of different aircraft noise spectra to determine A-level differences with elevation angle. The lateral attenuation based on the theoretical model showed near negligible attenuation above 5° elevation angle. The lateral attenuation based on the experimental data showed appreciably greater attenuation, but still less attenuation than the SAE model currently incorporated in the Integrated Noise Model (INM) aircraft noise computer program. Based on the experimental curves, a new generalized transition model was developed and is recommended as a replacement for the current NOISEMAP lateral transition algorithm.</p> | | | | | |
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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.

Administrative and technical monitor for this effort was Mr. Jerry D. Speakman of the Biodynamic Environmental 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. Jerry Speakman and the assistance of Ms. Emma Wilby, BBN, who prepared and exercised the analytical model computer programs.

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LATERAL ATTENUATION OF AIRCRAFT FLIGHT NOISE

1. INTRODUCTION

This report considers the lateral attenuation of aircraft flight noise with emphasis on the development of computational models for predicting aircraft noise during takeoffs and landings. In particular, the report looks at the expected variation in noise levels with elevation angle. Comparisons of different models are made in terms of the differences in A-levels for a flyover with the observer directly under the aircraft (an elevation angle of 90°) and for a flyover with the observer to one side of the flight track (elevation angle less the 90°). Comparisons are made using excess sound attenuation (ESA) values derived from theory and from field noise measurements. These are compared with the current lateral attenuation models incorporated in the NOISEMAP computer program (ref. 1) and the curve recommended by the SAE in reference 2.

The next section provides a background technical discussion. Section 3 describes the approach used in the study. The following sections present the results, discussion and recommendations.

2. BACKGROUND DISCUSSION

Many measurements of aircraft in flight are made with the aircraft flight path passing over or nearly over the ground observer. These measurements are typically adjusted for wave-divergence (spherical spreading) and atmospheric absorption to develop noise level predictions for different distances from the aircraft. When the ground position is laterally displaced from the projection of the flight path, additional attenuation may occur due to ground effects (surface absorption and reflection), meteorological effects such as wind, temperature gradients, and scattering by the atmosphere, and effects of the airplane installation, such as source shielding. In this report, this additional attenuation is referred to as lateral attenuation.

The geometrical model assumed in deriving lateral attenuation is shown schematically in Figure 1. Point Q on the flight track in the ground plane lies below the flight path. Point S on the flight path is located at the nearest distance of approach to Point Q. Point P is displaced normal to the flight path by lateral distance L. The distance between Point P and S is the slant range. The elevation angle B is defined in the figure.

Consider a situation such that the airplane is at point S' on an auxiliary flight path parallel to and above the previous flight path, so that $QS' = r$, the slant range of the previous case. In both cases, engine power setting, airplane configuration and airspeed are considered to be identical. The difference between the noise level L_Q at point Q when the airplane is flying along the auxiliary flight path and the noise level L_P at point P at the sideline when the airplane is flying along the original flight path is equal to $L_Q - L_P = \Lambda$. The noise level difference Λ , in decibels, is defined as the lateral attenuation with respect to point P.

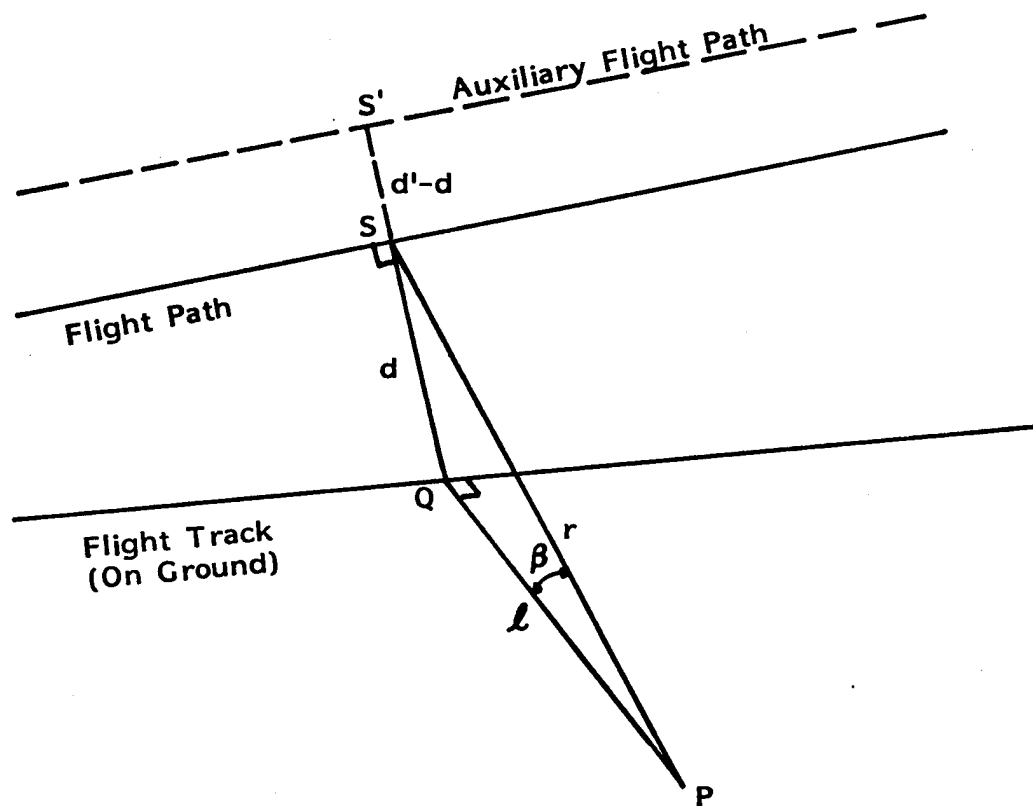


FIGURE 1. GEOMETRICAL MODEL FOR LATERAL ATTENUATION

In current aircraft noise prediction models such as NOISEMAP and the Integrated Noise Model (INM), the total lateral attenuation Λ is assumed to be a function of the elevation angle β times the lateral attenuation for over ground propagation ($\beta=0$).

The latter case will be termed "excess sound attenuation, (ESA)." Thus:

$$\Lambda = f_1 (1, \beta = 0), f_2 (\beta) \quad (1)$$

In the current NOISEMAP model, the excess sound attenuation ($\beta=0$) is dependent upon the aircraft noise spectra and the lateral distance. In the SAE model, currently incorporated in INM, a single ESA curve is used which is aircraft independent but which varies with distance.

Both the current SAE and NOISEMAP lateral attenuation models assume that the lateral attenuation adjustment to be applied to the basic noise data is the same when applied to maximum levels (maximum A-levels for example) or to integrated noise measures such as the sound exposure level.

3. ANALYSIS APPROACH

For this study, sets of sound spectrum-dependent lateral attenuation values derived from a theoretical model and from experimental field measurements were developed for different elevation angles. These sets of lateral attenuation values were applied to sets of one-third octave band spectra for different aircraft. The resulting differences in A-levels for these noise spectra (with and without the lateral attenuation applied) were tabulated and compared.

Nine sets of aircraft noise spectra were selected to provide a variety of spectrum shapes representing flyover noise levels produced by turbojet, turbofan and turboprop aircraft. Each spectral set consisted of one-third octave band spectra at various distances ranging from 250 feet to 31,500 feet. Eight spectra were selected from those from reference 3, 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 spectral set -- that for takeoff thrust for the Challenger 600, a business aircraft powered with a high bypass ratio turbofan -- was also selected. These spectra are identical to those used in the analysis of overground excess attenuation reported in reference 4.

Three sets of theoretical ESA values were developed, all based on the theoretical model described in detail in Appendix A of reference 5. An impedance value of 100 cgs rayls was selected for the computations since this value was found to give a reasonably good fit for the theoretical model when compared to experimental values of excess sound attenuation over a near-level grassy surface, as described in references 4 and 5.

Assuming a microphone height of 1.5m, sets of ESA values were computed for the following conditions:

1. A source located at a height of 400 ft. over a grassy surface with ESA values at the different elevation angles relative to the ESA for a microphone directly under the source.
2. As above, except the source height was 1500 ft.
3. As in (1) (i.e., source height of 400 ft.), but with all ESA values referenced to the ESA for an infinitely hard surface.

These ESA values are tabulated in Tables 1, 2 and 3. Inspection of the tables will show that the ESA values for source heights of 400 ft. and 1500 ft. are nearly the same, hence only the results for ESA values computed for a height of 400 ft. will be shown in report figures. Plots of the ESA values for the 400 ft. source height at elevation angles of 2, 5 and 10 degrees are shown in Figures 2, 3 and 4.

The set of experimental ESA values are based upon differences in noise spectra measured at various angles compared to the spectra measured directly under the aircraft (after adjustment for spherical spreading and air absorption). These data were acquired and analyzed by AMRL (as described in reference 6) for various level flight flyovers of the following aircraft:

A-10, C-135A, C-141, E-3A, F-5E, F-15, and F-18.

TABLE 1. THEORETICAL ESA VALUES FOR
ELEVATION ANGLE ANALYSES

RELATIVE ESA. R 100, 400 FT REFERENCE HEIGHT

| FREQ HZ | EXCESS SOUND ATTENUATION IN dB | | | | | | | | | |
|------------|--------------------------------|-------|--------|--------|--------|--------|--------|--------|--------|-------|
| | ANGLE IN DEGREES | | | | | | | | | |
| | 90 | 60 | 30 | 20 | 10 | 5 | 4 | 3 | 2 | 1 |
| 50 | 0 | -5.77 | -12.65 | -13.82 | -14.05 | -13.10 | -12.57 | -11.69 | -10.00 | -5.81 |
| 63 | 0 | 7.54 | -6.73 | -8.90 | -9.55 | -8.49 | -7.87 | -6.85 | -4.95 | -0.58 |
| 80 | 0 | 3.81 | 5.36 | 0.84 | -0.67 | 0.41 | 1.11 | 2.26 | 4.32 | 8.83 |
| 100 | 0 | 1.56 | 16.76 | 6.71 | 3.51 | 4.49 | 5.25 | 6.49 | 8.67 | 13.30 |
| 125 | 0 | -0.80 | 8.97 | 11.55 | 4.60 | 5.24 | 6.02 | 7.32 | 9.60 | 14.31 |
| 160 | 0 | -6.33 | -6.63 | 3.00 | -1.44 | -1.68 | -0.92 | 0.40 | 2.74 | 7.45 |
| 200 | 0 | 6.34 | -1.16 | 3.72 | 9.10 | 7.99 | 8.68 | 9.97 | 12.31 | 16.86 |
| 250 | 0 | -2.47 | -1.24 | -1.27 | 6.44 | 7.44 | 8.18 | 9.51 | 11.86 | 16.10 |
| 315 | 0 | 4.42 | 7.90 | -0.56 | 3.63 | 6.95 | 7.97 | 9.52 | 12.02 | 16.17 |
| 400 | 0 | -1.42 | -1.76 | 2.42 | -0.95 | 2.07 | 3.22 | 4.89 | 7.52 | 11.87 |
| 500 | 0 | -0.21 | 1.96 | 2.79 | -0.83 | 0.21 | 1.22 | 2.82 | 5.43 | 9.92 |
| 630 | 0 | 0.82 | -0.30 | -0.38 | 1.94 | -1.51 | -0.92 | 0.39 | 2.83 | 7.35 |
| 800 | 0 | -0.11 | 0.73 | 2.10 | 4.19 | -2.60 | -2.90 | -2.21 | -0.16 | 4.24 |
| 1000 | 0 | 0.43 | 0.68 | 1.09 | -1.06 | -0.81 | -2.90 | -3.32 | -1.94 | 2.16 |
| 1250 | 0 | 0.07 | 0.58 | 0.40 | 1.50 | 5.12 | -1.12 | -3.85 | -3.69 | -0.12 |
| 1600 | 0 | 0.53 | 0.52 | 0.93 | -0.99 | 0.44 | 6.49 | -1.92 | -4.49 | -2.01 |
| 2000 | 0 | 0.00 | 0.51 | 0.03 | 1.15 | -3.53 | -0.72 | 3.82 | -4.40 | -3.72 |
| 2500 | 0 | 0.42 | 0.68 | 0.60 | -0.39 | 1.85 | -4.13 | 0.49 | -2.07 | -4.92 |
| 3150 | 0 | -0.08 | 0.10 | -0.30 | -1.21 | -3.58 | 1.35 | -4.81 | 2.72 | -5.59 |
| 4000 | 0 | 0.16 | 0.10 | -0.14 | -1.63 | -1.09 | -4.07 | -0.84 | -2.97 | -5.02 |

TABLE 2. THEORETICAL ESA VALUES FOR
ELEVATION ANGLE ANALYSES

RELATIVE ESA, R 100, 1500 REFERENCE HEIGHT

| FREQ HZ | EXCESS SOUND ATTENUATION IN dB | | | | | | | | | |
|------------|--------------------------------|-------|--------|--------|--------|--------|--------|--------|-------|-------|
| | ANGLE IN DEGREES | | | | | | | | | |
| | 90 | 60 | 30 | 20 | 10 | 5 | 4 | 3 | 2 | 1 |
| 50 | 0 | -5.82 | -12.67 | -13.82 | -14.02 | -13.01 | -12.45 | -11.45 | -9.87 | -5.98 |
| 63 | 0 | 7.70 | -6.71 | -8.86 | -9.48 | -8.40 | -7.77 | -6.75 | -4.91 | -0.79 |
| 80 | 0 | 3.84 | 5.42 | 0.91 | -0.58 | 0.52 | 1.22 | 2.35 | 4.34 | 8.66 |
| 100 | 0 | 1.58 | 16.87 | 6.79 | 3.60 | 4.59 | 5.33 | 6.55 | 8.67 | 13.12 |
| 125 | 0 | -0.78 | 9.04 | 11.62 | 4.68 | 5.31 | 6.09 | 7.36 | 9.58 | 14.05 |
| 160 | 0 | -6.35 | -6.61 | 2.99 | -1.41 | -1.67 | -0.93 | 0.37 | 2.63 | 6.89 |
| 200 | 0 | 6.38 | -1.11 | 3.78 | 9.10 | 8.00 | 8.67 | 9.92 | 12.13 | 15.80 |
| 250 | 0 | -2.45 | -1.18 | -1.21 | 6.41 | 7.39 | 8.11 | 9.37 | 11.49 | 14.34 |
| 315 | 0 | 4.45 | 7.96 | -0.49 | 3.64 | 6.88 | 7.87 | 9.33 | 11.54 | 14.11 |
| 400 | 0 | -1.40 | -1.72 | 2.48 | -0.94 | 2.00 | 3.11 | 4.71 | 7.06 | 9.97 |
| 500 | 0 | -0.20 | 2.01 | 2.80 | -0.81 | 0.14 | 1.11 | 2.63 | 5.02 | 8.29 |
| 630 | 0 | 0.84 | -0.27 | -0.35 | 1.94 | -1.60 | -1.05 | 0.20 | 2.45 | 5.96 |
| 800 | 0 | -0.10 | 0.75 | 2.07 | 4.04 | -2.73 | -3.06 | -2.42 | -0.51 | 3.08 |
| 1000 | 0 | 0.44 | 0.68 | 1.07 | -1.17 | -1.01 | -3.09 | -3.54 | -2.23 | 1.24 |
| 1250 | 0 | 0.08 | 0.57 | 0.34 | 1.32 | 4.42 | -1.39 | -4.04 | -3.87 | -0.79 |
| 1600 | 0 | 0.53 | 0.48 | 0.82 | -1.18 | 0.06 | 4.97 | -2.15 | -4.50 | -2.34 |
| 2000 | 0 | -0.01 | 0.45 | -0.10 | 0.85 | -3.62 | -1.05 | 2.29 | -4.29 | -3.69 |
| 2500 | 0 | 0.40 | 0.59 | 0.44 | -0.60 | 1.08 | -4.01 | -0.32 | -2.38 | -4.39 |
| 3150 | 0 | -0.09 | 0.02 | -0.40 | -1.30 | -3.41 | 0.15 | -4.39 | -0.53 | -4.59 |
| 4000 | 0 | 0.15 | 0.05 | -0.18 | -1.56 | -1.44 | -3.63 | -1.80 | -3.16 | -4.15 |

TABLE 3. THEORETICAL ESA VALUES FOR
ELEVATION ANGLE ANALYSES

ESA RE HARD SURFACE. R 100, 400 FT REFERENCE HEIGHT

| FREQ HZ | EXCESS SOUND ATTENUATION IN dB | | | | | | | | | |
|------------|--------------------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| | ANGLE IN DEGREES | | | | | | | | | |
| | 90 | 60 | 30 | 20 | 10 | 5 | 4 | 3 | 2 | 1 |
| 50 | 15.88 | 10.11 | 3.23 | 2.06 | 1.83 | 2.78 | 3.31 | 4.20 | 5.88 | 10.07 |
| 63 | 11.96 | 19.51 | 5.23 | 3.07 | 2.42 | 3.47 | 4.09 | 5.12 | 7.01 | 11.38 |
| 80 | 3.95 | 7.76 | 9.31 | 4.76 | 3.27 | 4.36 | 6.06 | 6.21 | 8.27 | 12.77 |
| 100 | 0.91 | 2.47 | 17.68 | 7.63 | 4.42 | 5.41 | 6.17 | 7.40 | 9.59 | 14.21 |
| 125 | 1.50 | 0.71 | 10.48 | 13.05 | 6.10 | 6.74 | 7.53 | 8.83 | 11.10 | 15.81 |
| 160 | 10.30 | 3.97 | 3.67 | 13.30 | 8.87 | 8.62 | 9.38 | 10.70 | 13.04 | 17.75 |
| 200 | 2.53 | 8.87 | 1.36 | 6.25 | 11.62 | 10.51 | 11.20 | 12.50 | 14.84 | 19.38 |
| 250 | 4.00 | 1.54 | 2.76 | 2.73 | 10.45 | 11.44 | 12.18 | 13.51 | 15.87 | 20.11 |
| 315 | 0.83 | 7.25 | 10.73 | 2.27 | 6.46 | 9.78 | 10.81 | 12.35 | 14.85 | 19.00 |
| 400 | 4.63 | 3.22 | 2.87 | 7.06 | 3.68 | 6.70 | 7.85 | 9.53 | 12.15 | 16.50 |
| 500 | 3.96 | 3.75 | 5.93 | 6.75 | 3.14 | 4.18 | 5.18 | 6.78 | 9.39 | 13.88 |
| 630 | 3.92 | 4.75 | 3.62 | 3.54 | 6.86 | 2.41 | 3.01 | 4.32 | 6.76 | 11.28 |
| 800 | 4.52 | 4.41 | 5.26 | 6.63 | 8.72 | 1.92 | 1.62 | 2.32 | 4.37 | 8.76 |
| 1000 | 4.43 | 4.86 | 5.10 | 5.51 | 3.36 | 3.61 | 1.53 | 1.10 | 2.48 | 6.59 |
| 1250 | 4.71 | 4.78 | 5.29 | 5.11 | 6.20 | 9.83 | 3.59 | 0.86 | 1.02 | 4.59 |
| 1600 | 4.64 | 5.17 | 5.17 | 5.57 | 3.65 | 5.08 | 11.14 | 2.72 | 0.15 | 2.64 |
| 2000 | 4.92 | 4.91 | 5.43 | 4.95 | 6.07 | 1.39 | 4.19 | 8.73 | 0.51 | 1.19 |
| 2500 | 5.06 | 5.48 | 5.74 | 5.66 | 4.67 | 6.91 | 0.94 | 5.56 | 2.99 | 0.15 |
| 3150 | 5.31 | 5.23 | 5.41 | 5.01 | 4.10 | 1.73 | 6.66 | 0.50 | 8.03 | -0.28 |
| 4000 | 5.34 | 5.50 | 5.44 | 5.20 | 3.71 | 4.25 | 1.27 | 4.50 | 2.37 | 0.32 |

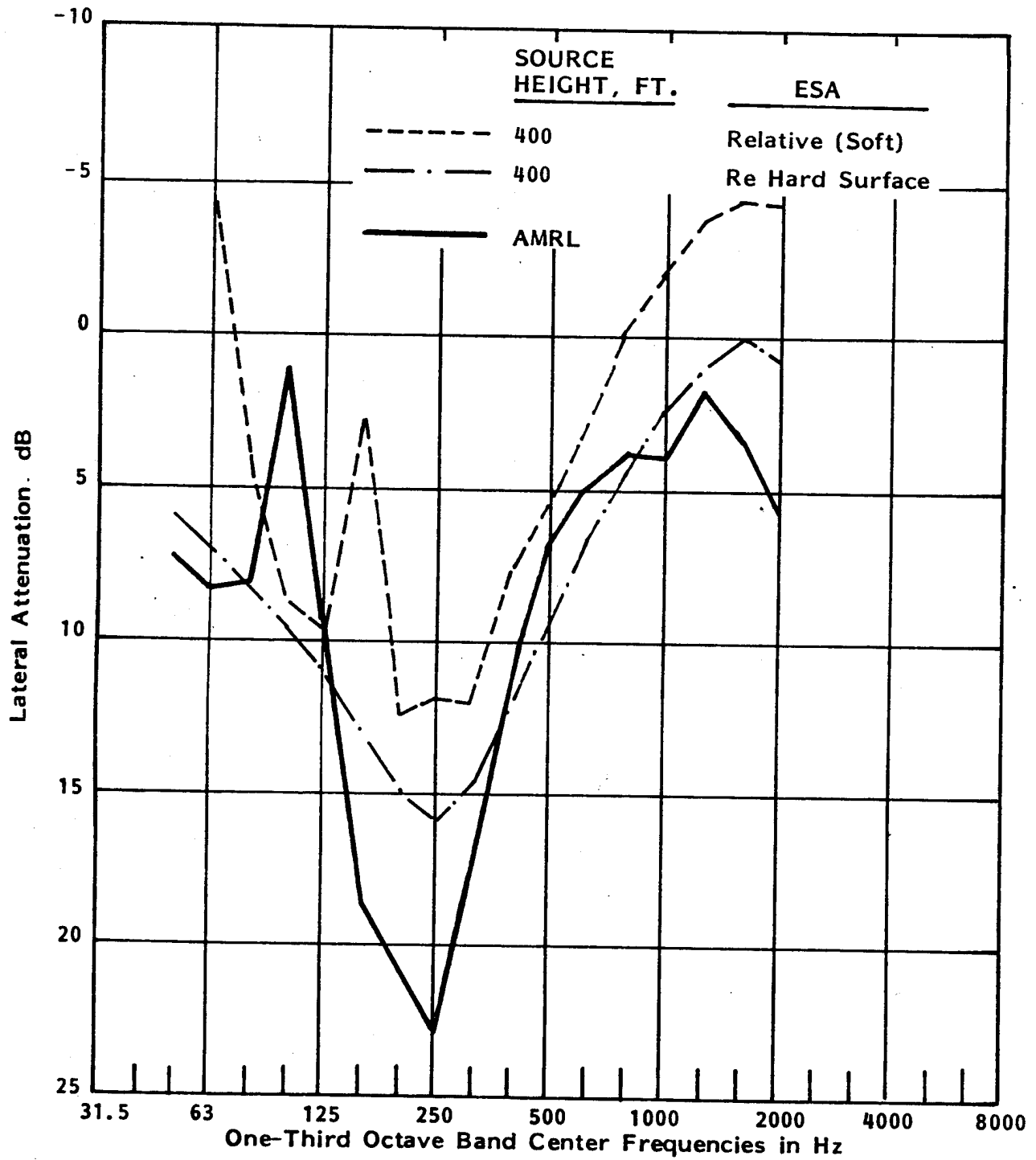


FIGURE 2. COMPARISON OF LATERAL ATTENUATION, 2° ELEVATION ANGLE

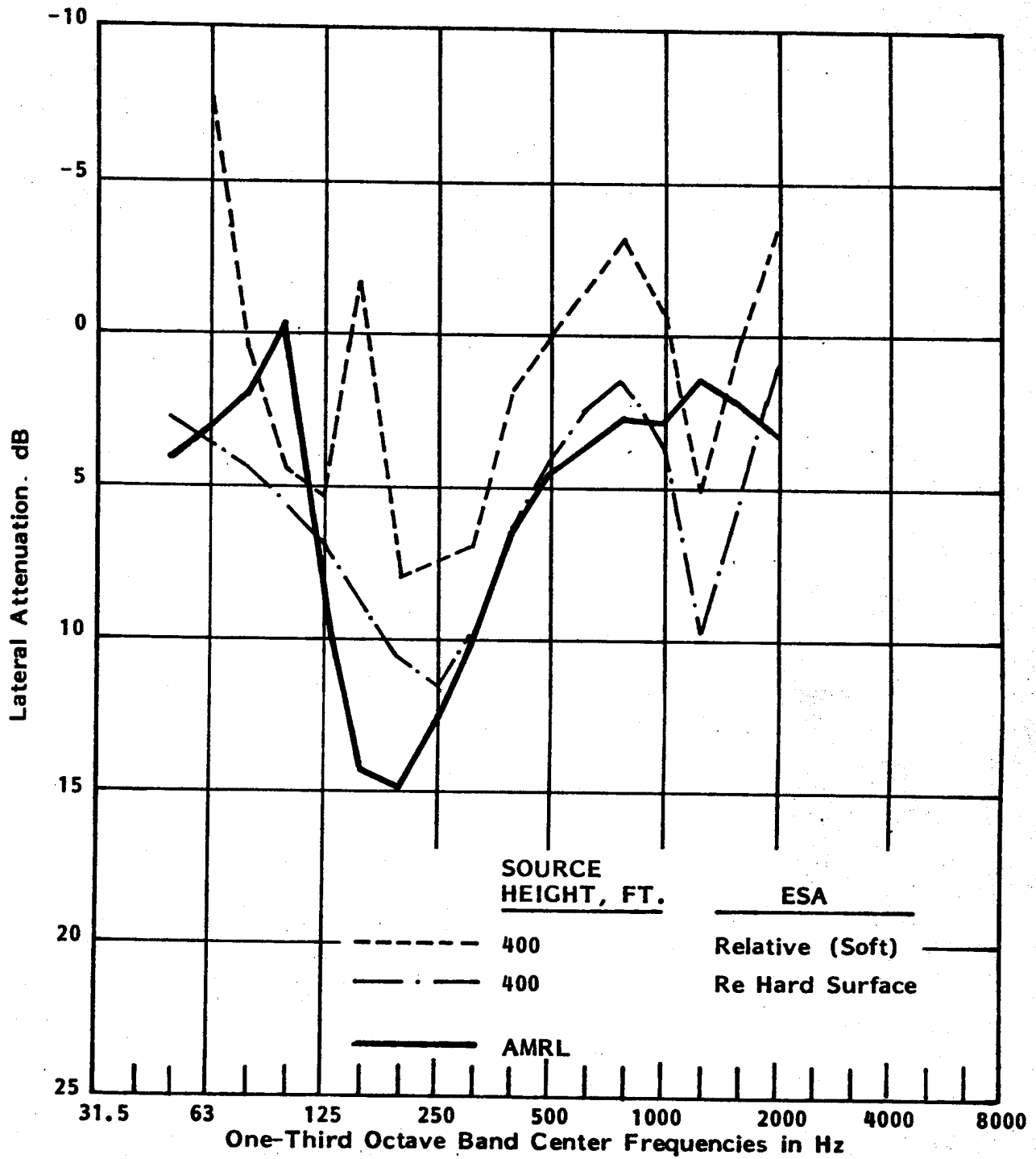


FIGURE 3. COMPARISON OF LATERAL ATTENUATION, 5° ELEVATION ANGLE

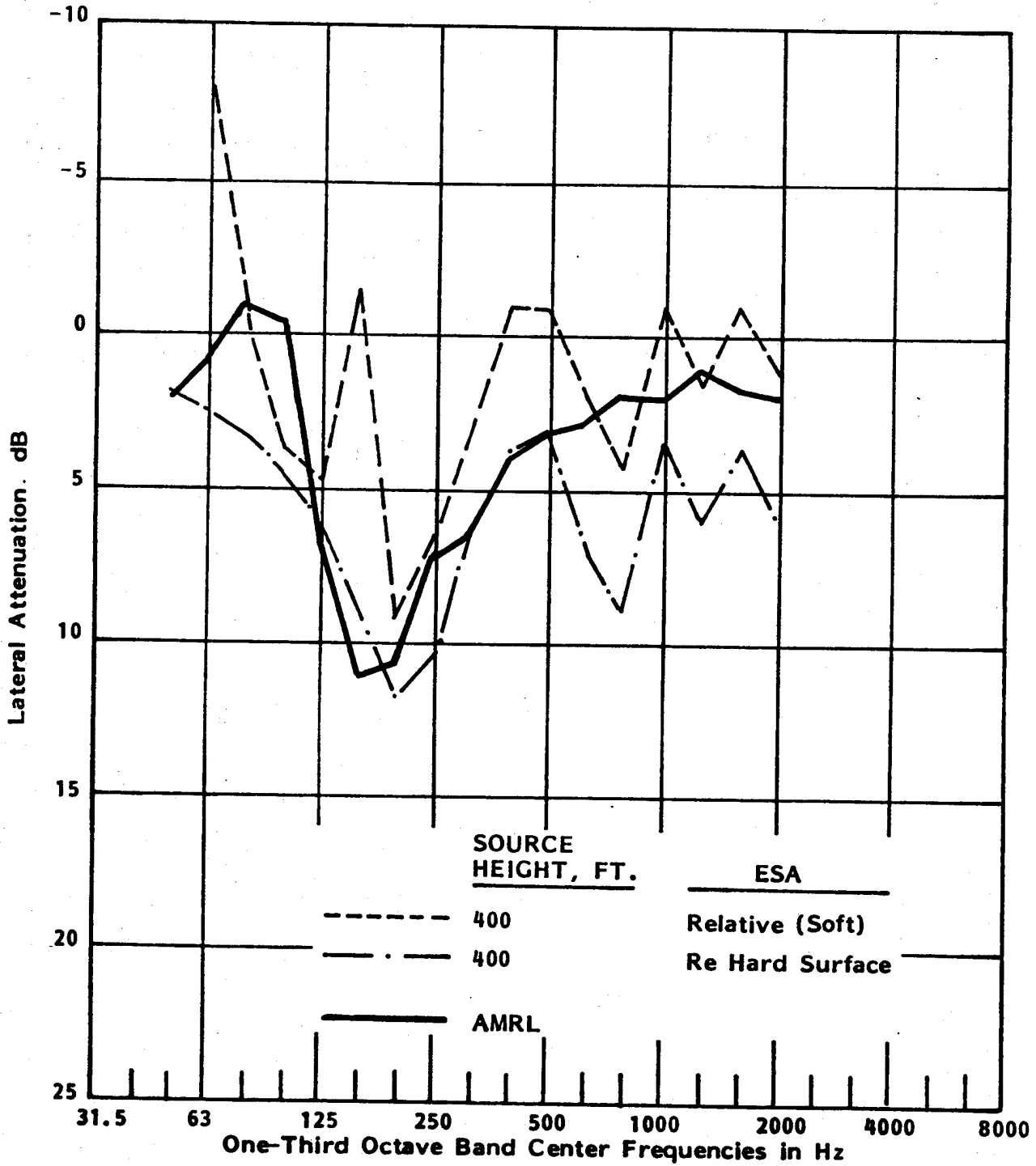


FIGURE 4. COMPARISON OF LATERAL ATTENUATION, 10° ELEVATION ANGLE

Average spectrum differences were provided by AMRL for angles of 2, 5, 10 and 20 degrees. Additional data for angles of 3 and 4 degrees were determined by interpolation. These experimental values are tabulated in Table 4. These values are also shown in Figures 2, 3 and 4 for elevation angles of 2, 5 and 10 degrees.

The sets of ESA values were then applied to the different aircraft noise spectra, assuming flyover heights (for $\beta = 0$) of 400 ft. and 1,000 ft. A-level differences were then computed for various angles with and without the ESA values applied to the spectra. For a given elevation angle, the noise spectra differ for the two assumed flyover heights. Hence, applying the same ESA values for a given angle to the two different spectra may result in differing A-level differences.

TABLE 4. EXPERIMENTAL (AMRL) ESA VALUES
FOR ELEVATION ANGLE ANALYSIS

EXCESS SOUND ATTENUATION IN dB

| FREQ HZ | ANGLE IN DEGREES | | | | | | | | |
|------------|------------------|----|----|-------|-------|-------|-------|-------|-------|
| | 90 | 60 | 30 | 20 | 10 | 5 | 4 | 3 | 2 |
| 50 | 0 | 0 | 0 | 1.10 | 2.10 | 4.00 | 5.10 | 6.20 | 7.30 |
| 63 | 0 | 0 | 0 | -0.50 | 0.80 | 3.20 | 4.90 | 6.60 | 8.30 |
| 80 | 0 | 0 | 0 | -2.10 | -1.00 | 2.00 | 4.03 | 6.07 | 8.10 |
| 100 | 0 | 0 | 0 | -0.60 | -0.50 | -0.30 | 0.13 | 0.57 | 1.00 |
| 125 | 0 | 0 | 0 | 4.50 | 6.70 | 8.40 | 8.93 | 9.47 | 10.00 |
| 160 | 0 | 0 | 0 | 7.70 | 11.00 | 14.30 | 15.77 | 17.23 | 18.70 |
| 200 | 0 | 0 | 0 | 6.70 | 10.60 | 14.90 | 16.83 | 18.77 | 20.70 |
| 250 | 0 | 0 | 0 | 3.10 | 7.10 | 12.80 | 16.20 | 19.60 | 23.00 |
| 315 | 0 | 0 | 0 | 3.60 | 6.40 | 10.10 | 12.40 | 14.70 | 17.00 |
| 400 | 0 | 0 | 0 | 2.00 | 4.00 | 6.50 | 8.03 | 9.57 | 11.10 |
| 500 | 0 | 0 | 0 | 2.10 | 3.20 | 4.60 | 5.33 | 6.07 | 6.80 |
| 630 | 0 | 0 | 0 | 1.50 | 2.80 | 3.70 | 4.10 | 4.50 | 4.90 |
| 800 | 0 | 0 | 0 | 1.50 | 1.90 | 2.80 | 3.13 | 3.47 | 3.80 |
| 1000 | 0 | 0 | 0 | 0.90 | 2.00 | 2.90 | 3.27 | 3.63 | 4.00 |
| 1250 | 0 | 0 | 0 | 1.30 | 1.00 | 1.40 | 1.53 | 1.67 | 1.80 |
| 1600 | 0 | 0 | 0 | 1.10 | 1.70 | 2.20 | 2.57 | 2.93 | 3.30 |
| 2000 | 0 | 0 | 0 | 1.10 | 1.90 | 3.20 | 4.03 | 4.87 | 5.70 |

4. RESULTS AND DISCUSSION

Results

Results of the analysis are summarized in Figures 5, 6 and 7, and in Tables 5 and 6. Figure 5 shows the average A-level differences as a function of angle for the theoretical ESA values referenced to a microphone over a grassy surface. Figure 6 shows the average A-level differences for ESA values referenced to a hard surface. The results shown in Figures 5 and 6 are also tabulated in Table 5. (This table also shows the results for the ESA values calculated for a 1500 ft. source height.) In addition, the table shows the maximum and minimum A-level differences observed among the different noise spectra.

Figure 7 shows the A-level differences for the AMRL excess attenuation values. These results are also tabulated in Table 6, together with the maximum and minimum A-level differences achieved among the different aircraft noise spectra.

Discussion

The A-level differences calculated with the theoretical ESA values include only the reflection off a flat plane of finite impedance and do not, of course, include any shielding effects due to airframe geometry nor any effects due to scattering and turbulence in propagation through a non-uniform lower atmosphere. Hence, one would anticipate that the theoretical values would be lower than the experimental values. And this, indeed, is the case. (See comparison with either the SAE curves or the curves based on the experimental ESA values.) It is clear from the theoretical model that lateral attenuation due to reflection from the ground surface only becomes important (exceeds approximately 2 dB) at elevation angles of less than 5 degrees and that the attenuation due to surface reflection is essentially negligible at higher angles.

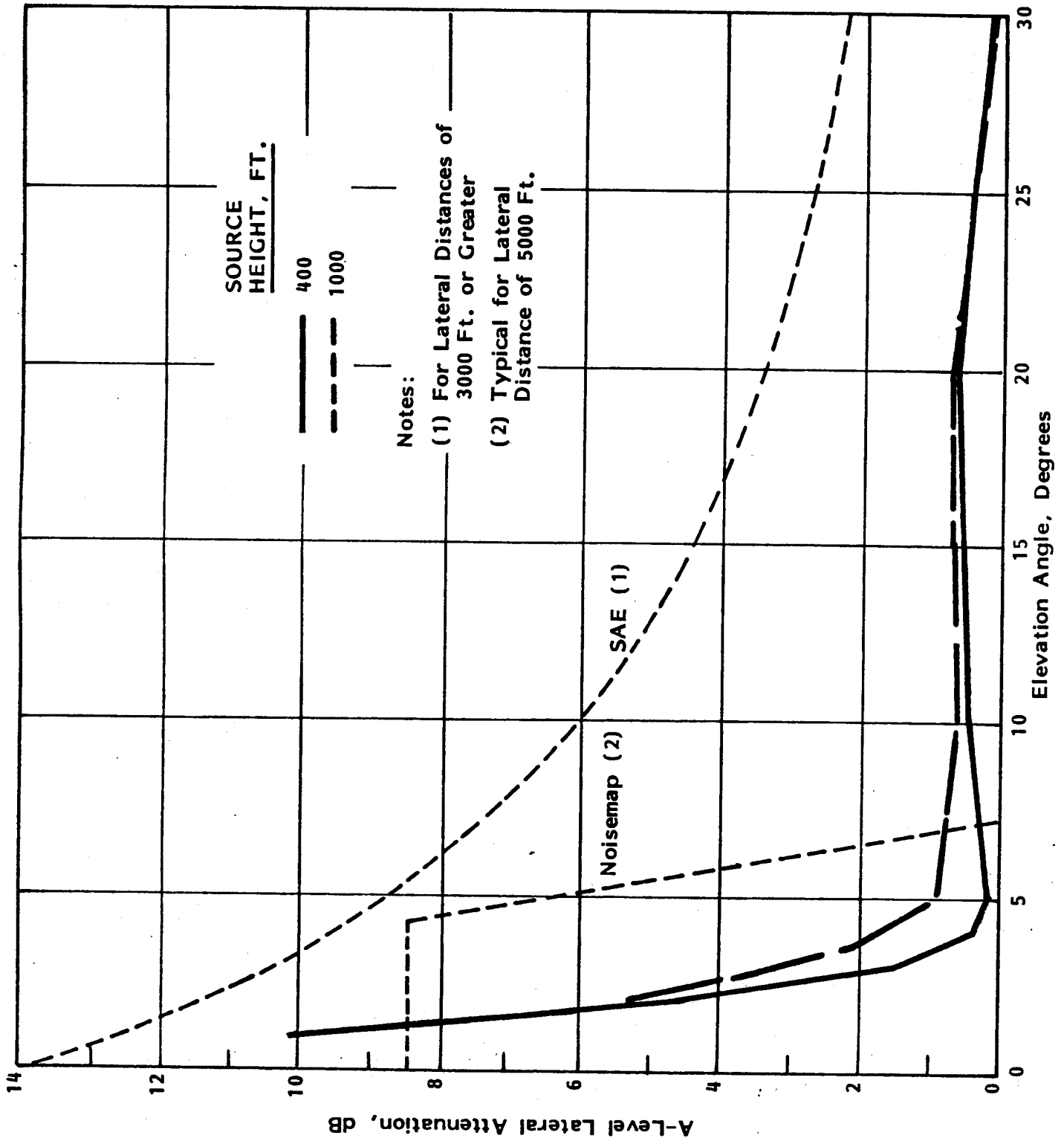


FIGURE 5. COMPARISON OF A-LEVEL LATERAL ATTENUATION VS ANGLE - THEORETICAL ATTENUATION VALUES RE GRASSY SURFACE REFERENCE

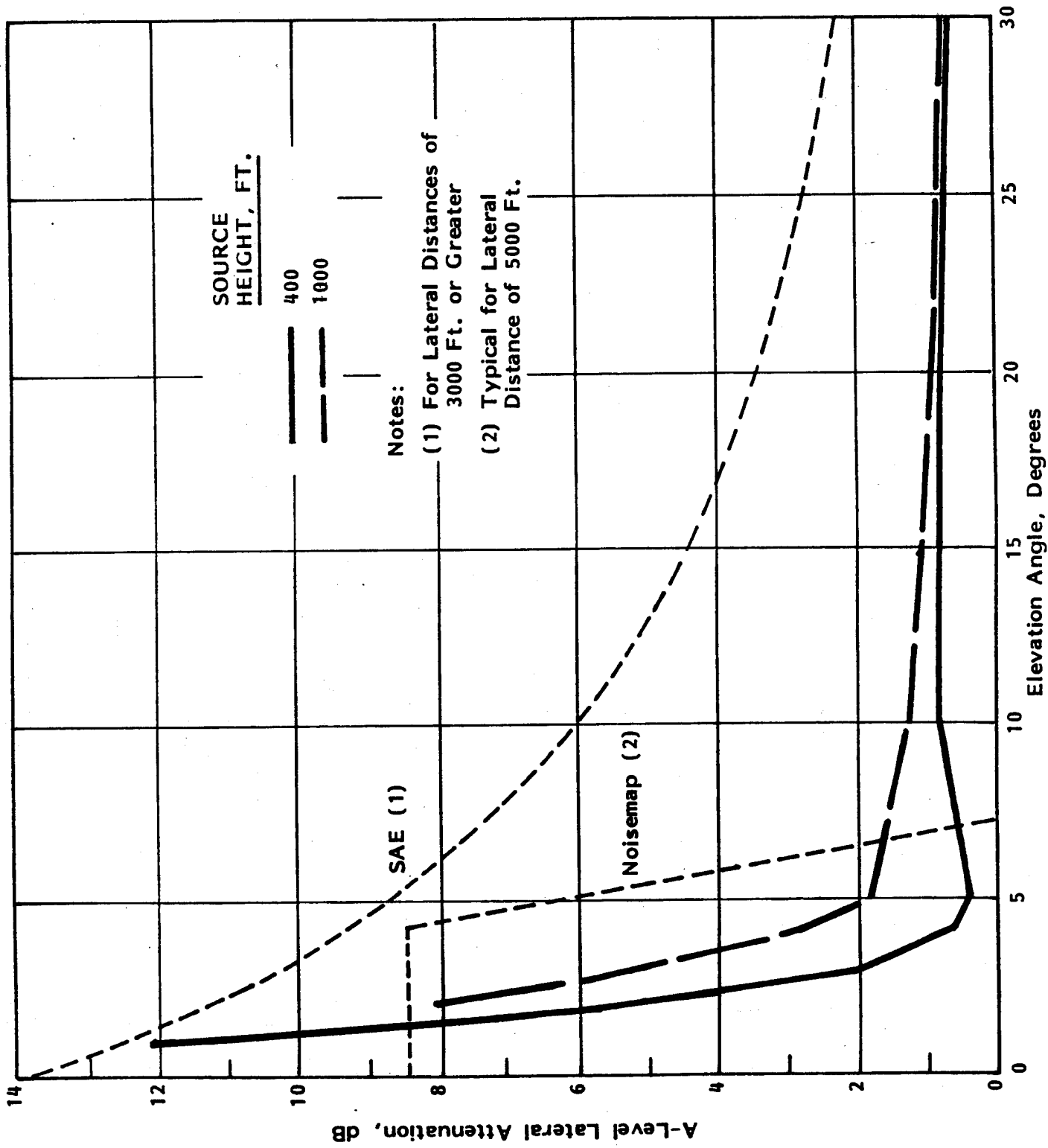


FIGURE 6. COMPARISON OF A-LEVEL LATERAL ATTENUATION VS ANGLE - THEORETICAL ATTENUATION VALUES RE HARD SURFACE REFERENCE

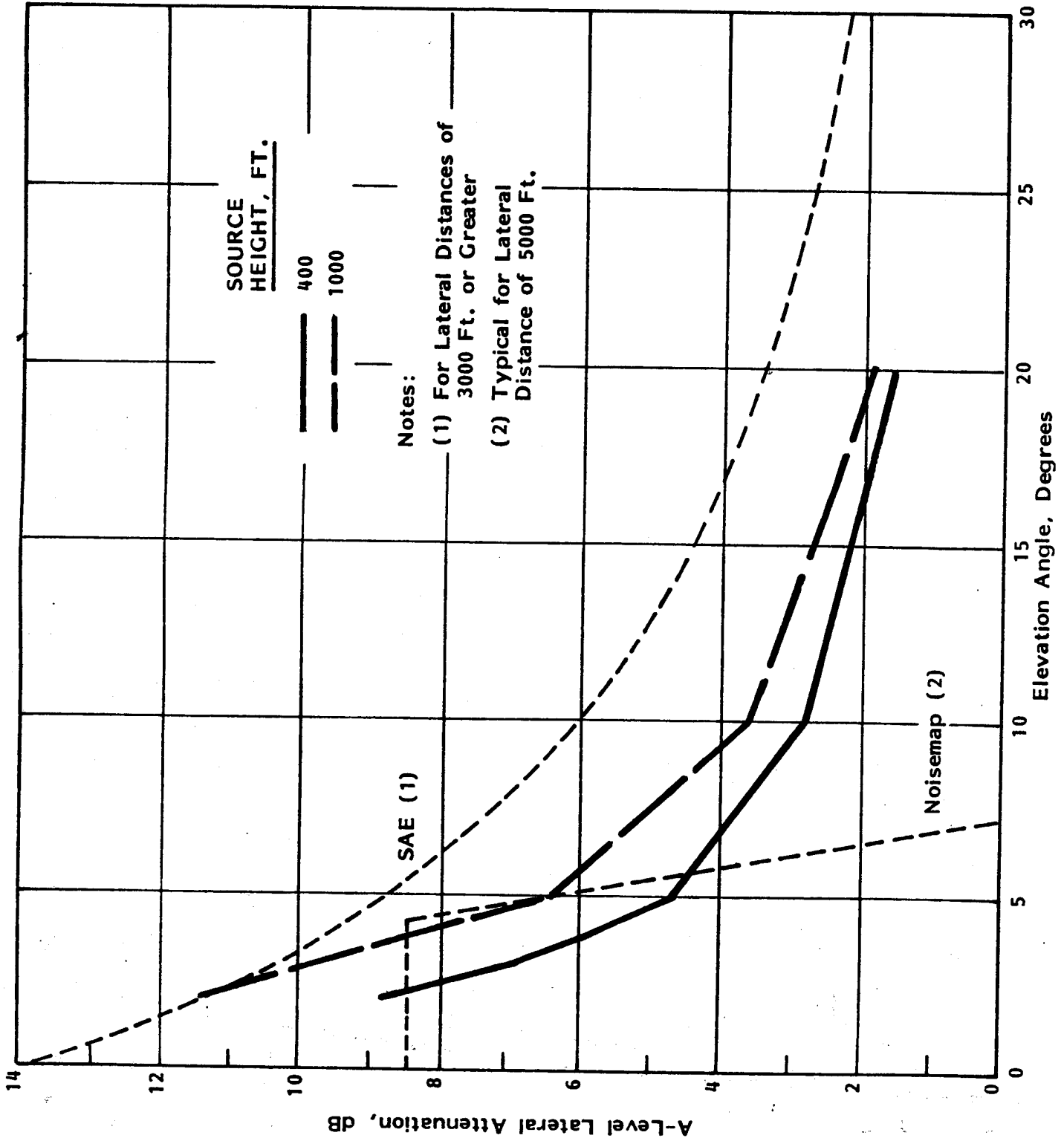


FIGURE 7. COMPARISON OF A-LEVEL LATERAL ATTENUATION VS ANGLE - AMRL ATTENUATION VALUES

Table 5. A-Level Lateral Attenuation
Based on Theoretical ESA Values

| A-LEVEL ESA DIFFERENCES VS ANGLE | | | | | | | | | | | |
|----------------------------------|------------|------------------|-------|------|------|------|-------|-------|------|------|-------|
| AVERAGE VALUES | | | | | | | | | | | |
| A/C HEIGHT | ESA VALUES | ANGLE IN DEGREES | | | | | | | | | |
| | | 90 | 60 | 30 | 20 | 10 | 5 | 4 | 3 | 2 | 1 |
| 400' | 400'R | 0 | 0.03 | 0.20 | 0.69 | 0.52 | 0.21 | 0.41 | 1.51 | 4.62 | 10.14 |
| | 1500'R | 0 | 0.04 | 0.19 | 0.67 | 0.46 | 0.12 | 0.30 | 1.38 | 4.41 | 9.45 |
| | 400'A | 0 | 0.39 | 0.59 | 0.75 | 0.83 | 0.42 | 0.65 | 1.83 | 5.31 | 12.07 |
| 1000' | 400'R | 0 | -0.01 | 0.11 | 0.76 | 0.66 | 0.95 | 1.77 | 3.33 | 5.40 | |
| | 1500'R | 0 | 0.00 | 0.12 | 0.76 | 0.64 | 0.89 | 1.71 | 3.25 | 5.25 | |
| | 400'A | 0 | 0.46 | 0.66 | 0.86 | 1.23 | 1.82 | 2.95 | 5.00 | 8.01 | |
| A-LEVEL ESA DIFFERENCES VS ANGLE | | | | | | | | | | | |
| MAXIMUM AND MINIMUM VALUES | | | | | | | | | | | |
| A/C HEIGHT | ESA VALUES | ANGLE IN DEGREES | | | | | | | | | |
| | | 90 | 60 | 30 | 20 | 10 | 5 | 4 | 3 | 2 | 1 |
| 400' | 400'A MAX | 0 | 0.74 | 1.22 | 1.13 | 1.68 | 1.47 | 1.84 | 3.25 | 7.10 | 13.50 |
| | MIN | 0 | 0.17 | 0.32 | 0.36 | 0.07 | -0.29 | -0.35 | 0.39 | 3.71 | 9.15 |
| 1000' | 400'A MAX | 0 | 0.88 | 1.30 | 1.18 | 2.05 | 2.95 | 4.48 | 6.63 | 9.32 | |
| | MIN | 0 | 0.18 | 0.31 | 0.46 | 0.57 | 0.72 | 1.63 | 2.84 | 4.58 | |

Table 6. A-Level Lateral Attenuation
Based on Experimental (AMRL) ESA Values

A-LEVEL ESA DIFFERENCES VS ANGLE

AVERAGE VALUES-AMRL

| A/C HEIGHT | ESA VALUES | ANGLE IN DEGREES | | | | | | | | |
|---------------|---------------|------------------|----|----|------|------|------|------|------|-------|
| | | 90 | 60 | 30 | 20 | 10 | 5 | 4 | 3 | 2 |
| 400' | AMRL | 0 | 0 | 0 | 1.62 | 2.83 | 4.70 | 5.71 | 6.96 | 8.99 |
| 1000' | AMRL | 0 | 0 | 0 | 1.87 | 3.59 | 6.45 | 8.02 | 9.92 | 11.44 |

A-LEVEL ESA DIFFERENCES VS ANGLE

MAXIMUM AND MINIMUM VALUES-AMRL

| A/C HEIGHT | ESA VALUES | ANGLE IN DEGREES | | | | | | | | |
|---------------|---------------|------------------|----|----|------|------|------|-------|-------|-------|
| | | 90 | 60 | 30 | 20 | 10 | 5 | 4 | 3 | 2 |
| 400' | MAX | 0 | 0 | 0 | 2.04 | 3.41 | 5.45 | 6.67 | 8.32 | 10.84 |
| | MIN | 0 | 0 | 0 | 1.35 | 2.35 | 3.89 | 4.70 | 5.64 | 7.35 |
| 1000' | MAX | 0 | 0 | 0 | 2.24 | 4.30 | 7.94 | 10.09 | 12.59 | 14.64 |
| | MIN | 0 | 0 | 0 | 1.47 | 2.84 | 4.92 | 6.27 | 7.43 | 7.89 |

In general, one can say that the relatively large values of lateral attenuation observed at angles of below about 5 degrees can largely be accounted for in terms of surface reflection effects. However, at higher angles, the lateral attenuation observed experimentally is appreciably larger than can be accounted for by simple reflection effects.

The lateral attenuation differences based on the experimental AMRL data are considerably greater than those based on the theoretical model at all elevation angles. The A-level lateral attenuations for both the theoretical and AMRL ESA data are consistently greater for the aircraft height of 1000 ft. compared to 400 ft.*

Comparison of the excess attenuation based on the experimental AMRL values show ESA values that are lower than the SAE curve for angles greater than about 3 degrees, with the experimental values falling approximately 2 dB below the SAE curve throughout most of the angular range above 3 degrees.

*This can be explained, in large part, in terms of the greater changes in flyover noise spectrum shape vs. elevation angle as flyover height increases. A given elevation angle change involves greater distance changes as flyover height increases. As discussed in Reference 4, the greater distance changes reduce higher frequency levels more than the mid- or low-frequency levels, hence result in somewhat greater A-level changes for a given set of ESA spectrum values.

The SAE curve represents an arbitrary averaging of data from a large number of sources and includes results of measurements made under varying circumstances and test arrangements. The data also included results using different noise measures, including integrated measures such as EPNL (effective perceived noise level) and SEL, as well as maximum perceived noise levels and A-levels. In the development of the SAE curve, it was noted that the lateral attenuation curves developed by the Air Force from measured flyover data for military aircraft (primarily in terms of SEL's) fell below the average SAE curve. The current results are consistent with that earlier finding.

5. RECOMMENDATIONS

The current NOISEMAP algorithms for handling the lateral attenuation provide a relatively crude transition between air-to-ground and ground-to-ground ($\beta=0$) conditions, as Figure 7 makes clear. On the other hand, the SAE curve provides lateral attenuation that, for elevation angles above about 3 or 4 degrees, is in excess of that observed experimentally in the flyover noise measurements undertaken by AMRL. Further, the SAE curve is tied to an arbitrary excess attenuation curve that is not aircraft-dependent.

Recommendations for the over-ground attenuation model for NOISEMAP ($\beta=0$) are discussed in reference 4. If it assumed that those recommendations are carried out to the extent that any NOISEMAP excess attenuation model will be noise spectrum dependent and hence vary with distance, aircraft type and power setting, what this report should consider is the transition between that excess attenuation curve ($\beta=0$) and the lateral attenuation for elevation angles greater than zero.

It is believed that the AMRL experimental results provide a reasonable basis for developing an improved transition model for varying elevation angles. Hence, it is recommended that the shape of the A-level lateral attenuation curve derived from the AMRL experimental results (see Figure 7) be used as the basis for an improved lateral attenuation transition curve. Assuming that the average curves given in this report represent a reasonable sampling of noise spectra for military aircraft, one can develop a generalized transition curve based on an average of the two curves shown in Figure 7. Such a transition curve is shown in Figure 8, compared with the current NOISEMAP transition.

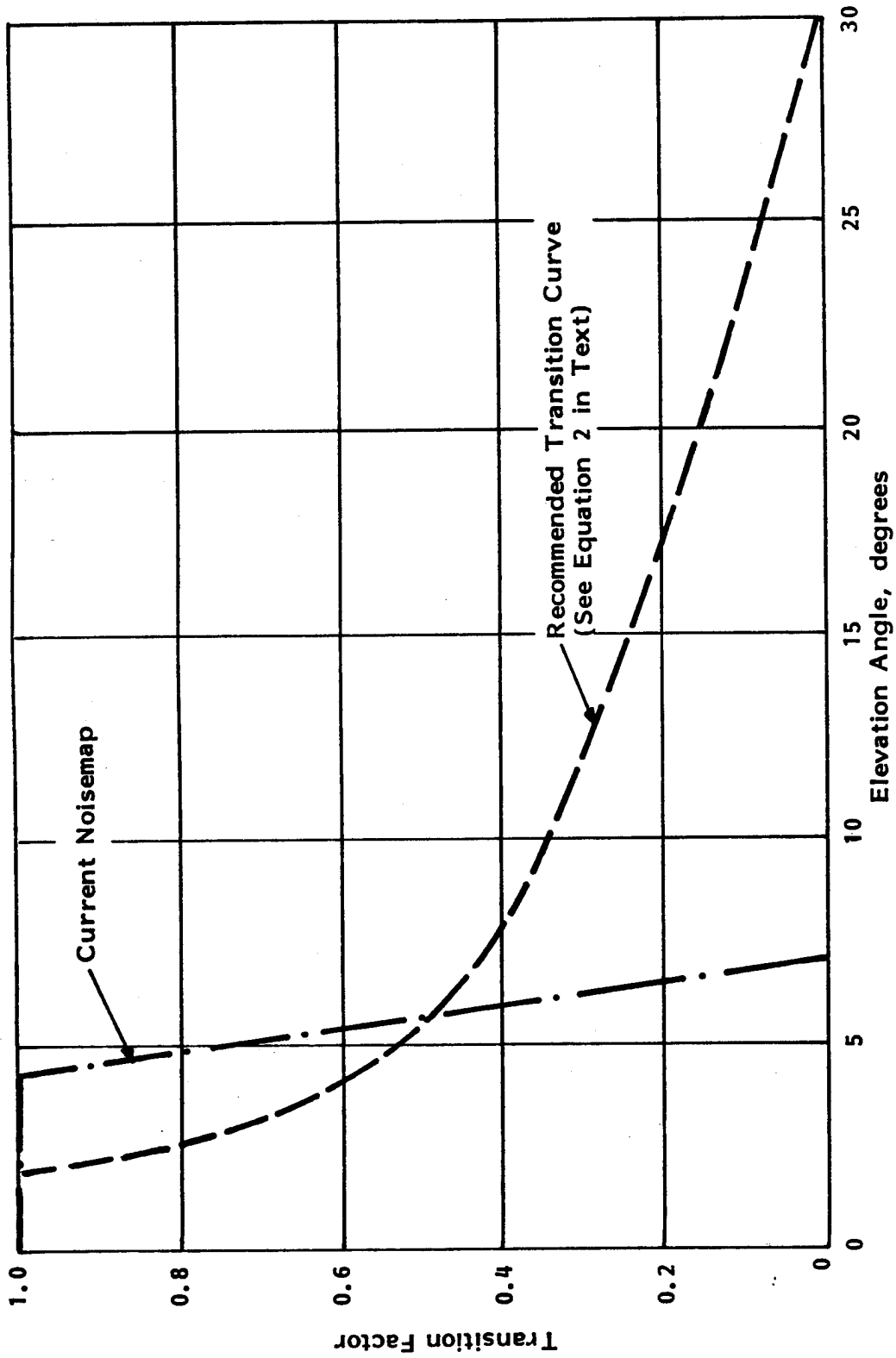


FIGURE 8. COMPARISON OF TRANSITIONS FROM GROUND TO AIR ATTENUATION

The curve of Figure 8 is based upon the following equation:

$$Y = 0.397 - 0.01405 \beta + 1.45 \beta^{-1.20} \quad (2^\circ \leq \beta \leq 30^\circ) \quad (2)$$

$$\text{and } Y = 1 \quad (0^\circ \leq \beta \leq 2^\circ)$$

$$Y = 0 \quad (\beta \geq 30^\circ)$$

And, as in the current NOISEMAP and SAE models, Y is used as a multiplier applied to the over-ground attenuation calculated for β at or near zero.

Note that the equation (2) does not modify the over-ground attenuation until the calculated elevation angle exceeds two degrees. This takes into account the lack of experimental data at very small elevation angles (less than 2 degrees).

In comparison with the current NOISEMAP model, the transition curve of Figure 8 provides less lateral attenuation between 2 and 5.7 degrees, and greater attenuation at angles between 5.7 and 30 degrees.

Two examples utilizing the curve of Figure 8 are presented in Figure 9. This figure shows the lateral attenuation based on equation (2) assuming that the excess attenuation ($\beta=0$) is a typical NOISEMAP value for a lateral distance of 5000 ft. or is the maximum value given by the SAE model (13.86 dB). In the latter case, the recommended curve would provide lateral attenuation greater than the SAE transition curve for elevation angles between zero and 3 degrees, and less lateral attenuation for higher elevation angles.

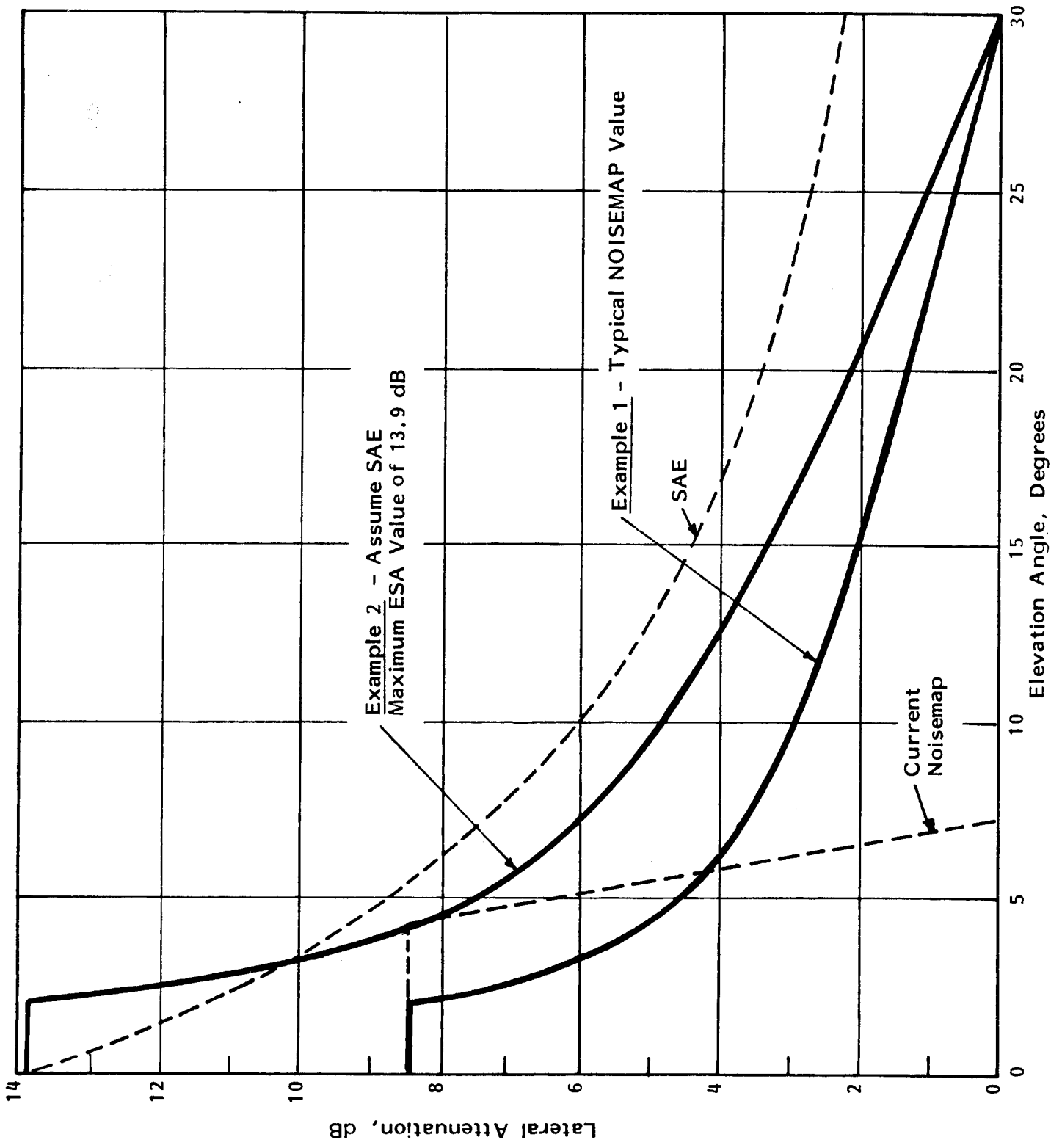


FIGURE 3. EXAMPLE OF RECOMMENDED LATERAL ATTENUATION CURVES

REFERENCES

1. D. E. Bishop, W. J. Galloway, "Community Noise Exposure Resulting from Aircraft Operations: Acquisition and Analysis of Aircraft Noise and Performance Data," Air Force AMRL-TR-73-107, August 1975.
2. SAE Aerospace Information Report (AIR) 1751, "Prediction Method for Lateral Attenuation of Airplane Noise during Takeoff and Landing," March 30, 1981.
3. J. D. Speakman, R. G. Powell, J. N. Cole, "Community Noise Exposure Resulting from Aircraft Operations: Acoustic Data on Military Aircraft," AMRL-TR-73-110, November 1977.
4. D. E. Bishop, "Overground Excess Sound Attenuation (ESA), Volume 3: Application of ESA Data in NOISEFILE," AFAMRL-TR-84-017, December 1984.
5. D. E. Bishop, "Overground Excess Sound Attenuation (ESA), Volume 2: Analysis of Data for Flat Grassy Terrain Conditions," Air Force AFAMRL-TR-84-017 Vol. 2, February 1984.
6. J. D. Speakman, "Measurement of Lateral Noise Levels Generated by Military Aircraft", Air Force AMRL unpublished report, 1982.