AL-TR-1991-0126

AD-A255 963

2

DTIC
S ELECTE D
OCT 0 1 1992
A

ARMSTRONG LABORATORY

EVALUATION OF THREE MODELS USED FOR PREDICTING NOISE PROPAGATED LONG DISTANCES OVERGROUND

W. R. Lundberg

OCCUPATIONAL & ENVIRONMENTAL HEALTH DIRECTORATE
BIOENVIRONMENTAL ENGINEERING DIVISION

SEPTEMBER 1991

INTERIM REPORT FOR THE PERIOD AUGUST 1990 - SEPTEMBER 1991

92 9 30 005

404167

92-26190

44p8

AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433-6573

NOTICES

Please do not request copies of this report from the Armstrong Laboratory. Additional copies may be purchased from:

National Technical Information Service
5285 Port Royal Road
Springfield VA 22161

Federal Government agencies and their contractors registered with Defense Technical Information Center should direct requests for copies of this report to:

Defense Technical Information Center
Cameron Station
Alexandria VA 22314

TECHNICAL REVIEW AND APPROVAL

AL-TR-1991-0126

This report has been reviewed by the Office of Public Affairs (PA) and is releasable to the 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.

Peter A. Lurker

PETER A. LURKER, Lt Col, USAF, BSC
Acting Director
Biodynamics and Biocommunications Division
Armstrong Laboratory

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
September 1991

3. REPORT TYPE AND DATES COVERED
Interim Report August 1990-September 199

4. TITLE AND SUBTITLE
Evaluation of Three Models used for Predicting Noise Propagated Long Distances Overground

5. FUNDING NUMBERS
PE: 62202F
PR: 7231
TA: 34
WU: 15

6. AUTHOR(S)
W.R. Lundberg

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Noise Effects Branch, Bioenvironmental Engineering Division
Occupational & Environmental Health Directorate
Armstrong Laboratory
Wright-Patterson AFB OH 45433-6573

8. PERFORMING ORGANIZATION REPORT NUMBER
AL-TR-1991-0126

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE
A

13. ABSTRACT *(Maximum 200 words)*

Pershing II missile elimination noise measurements were used as the basis for comparing three noise prediction programs' ground-to-ground propagation modeling approaches. The effects of atmospheric refraction, atmospheric absorption and ground impedance are considered. The noise models were compared because they are currently in use, in different venues, for environmental noise propagation modeling. The respective strong points of each model are emphasized. The results are used to delineate the needs for development of a model which produces both rapid and physically detailed predictions.

14. SUBJECT TERMS

Acoustics	Propagation
Environmental Noise	Noise Modeling

15. NUMBER OF PAGES

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

NSN 7540-01-280-5500

Standard Form 298 (Rev 2-89)
Prescribed by ANSI Std Z39-18
298-102

GENERAL INSTRUCTIONS FOR COMPLETING SF 298

The Report Documentation Page (RDP) is used in announcing and cataloging reports. It is important that this information be consistent with the rest of the report, particularly the cover and title page. Instructions for filling in each block of the form follow. It is important to ***stay within the lines*** to meet ***optical scanning requirements***.

Block 1. Agency Use Only *(Leave blank)*.

Block 2. Report Date. Full publication date including day, month, and year, if available (e.g. 1 Jan 88). Must cite at least the year.

Block 3. Type of Report and Dates Covered. State whether report is interim, final, etc. If applicable, enter inclusive report dates (e.g. 10 Jun 87 - 30 Jun 88).

Block 4. Title and Subtitle. A title is taken from the part of the report that provides the most meaningful and complete information. When a report is prepared in more than one volume, repeat the primary title, add volume number, and include subtitle for the specific volume. On classified documents enter the title classification in parentheses.

Block 5. Funding Numbers. To include contract and grant numbers; may include program element number(s), project number(s), task number(s), and work unit number(s). Use the following labels:

C - Contract
G - Grant
PE - Program Element
PR - Project
TA - Task
WU - Work Unit Accession No.

Block 6. Author(s). Name(s) of person(s) responsible for writing the report, performing the research, or credited with the content of the report. If editor or compiler, this should follow the name(s).

Block 7. Performing Organization Name(s) and Address(es). Self-explanatory.

Block 8. Performing Organization Report Number. Enter the unique alphanumeric report number(s) assigned by the organization performing the report.

Block 9. Sponsoring/Monitoring Agency Name(s) and Address(es). Self-explanatory.

Block 10. Sponsoring/Monitoring Agency Report Number. ***(If known)***

Block 11. Supplementary Notes. Enter information not included elsewhere such as: Prepared in cooperation with...; Trans. of...; To be published in.... When a report is revised, include a statement whether the new report supersedes or supplements the older report.

Block 12a. Distribution/Availability Statement. Denotes public availability or limitations. Cite any availability to the public. Enter additional limitations or special markings in all capitals (e.g. NOFORN, REL, ITAR).

DOD - See DoDD 5230.24, "Distribution Statements on Technical Documents."
DOE - See authorities.
NASA - See Handbook NHB 2200.2.
NTIS - Leave blank.

Block 12b. Distribution Code.

DOD - Leave blank.
DOE - Enter DOE distribution categories from the Standard Distribution for Unclassified Scientific and Technical Reports.
NASA - Leave blank.
NTIS - Leave blank.

Block 13. Abstract. Include a brief *(Maximum 200 words)* factual summary of the most significant information contained in the report.

Block 14. Subject Terms. Keywords or phrases identifying major subjects in the report.

Block 15. Number of Pages. Enter the total number of pages.

Block 16. Price Code. Enter appropriate price code *(NTIS only)*.

Blocks 17. - 19. Security Classifications. Self-explanatory. Enter U.S. Security Classification in accordance with U.S. Security Regulations (i.e., UNCLASSIFIED). If form contains classified information, stamp classification on the top and bottom of the page.

Block 20. Limitation of Abstract. This block must be completed to assign a limitation to the abstract. Enter either UL (unlimited) or SAR (same as report). An entry in this block is necessary if the abstract is to be limited. If blank, the abstract is assumed to be unlimited.

★U.S.GPO 1990 0 273-271

PREFACE

This study was performed for Armstrong Laboratory at Wright-Patterson Air Force Base, Ohio, under Project/Task 723134, Exploratory Noise and Sonic Boom Research by the Noise Effects Branch, Bioenvironmental Engineering Division.

The author appreciates the technical guidance and support of Mr Jerry Speakman, and the expertise and programs provided by Dr Mike White of the Army Construction Engineering Reseach Laboratory and Dr Richard Raspet of the University of Mississippi. Final preparation of the report by Ms Jackie Brennaman and Ms Bea Heflin is acknowledged.

TABLE OF CONTENTS

LIST OF FIGURES

Comparison of 1/3 Octave Band SPL Spectra:

LIST OF TABLES

Number Page

Chapter 1

DESCRIPTION OF THE PUEBLO ARMY DEPOT ACTIVITY ENVIRONMENTAL NOISE SURVEY

The Pershing II missile elimination noise was evaluated by the Army Environmental Hygiene Agency (AEHA) as a part of an Army Installation Compatible Use Zone (ICUZ) Program, and summarized in the Pueblo Army Depot Activity (PUADA) Report (Ref 1). "The purpose of the ICUZ Program is to safeguard the installation's mission capabilities from offpost encroachment of land uses which are not compatible with the noise environment" (ibid p.9). In order to achieve this goal, a conservative approach to estimate the noise environment was planned. The measurement protocol called for monitoring noise only when the measurement sites were downwind of the missile firing stand. The A-weighted Day-Night average sound Level (DNL) contours were calculated using the highest recorded noise levels, assuming five 50-second firings per day.

A limited amount of information was given in the PUADA report to define the propagation conditions. The only documented source of information regarding the source height was a diagram of the missile firing stand, from which a source height of between 5 and 7 meters was inferred. The rocket motor plume is actually a volume acoustic source, so an assumption of a point source was made for modeling the far acoustic field. The site locations and propagation distances were determined by examining the map provided with the PUADA report, as follows: Site 5 = 790m, Site 6 = 1610m, Site 7 = 2540m from the source. The ground surface's effective flow resistivity was estimated empirically based on the acoustic measurements, see Chapter 4. The receiver height was assumed to be that of a typical hand-held noise monitor (1-1.5m). The modeled source and receiver heights of 5 and 1 meters, respectively, were based on estimates given by Army personnel.

Additional information was provided by Dr Nelson Lewis (AEHA) to document the atmospheric propagation conditions and the measured average 1/3 octave band Sound Pressure Level (SPL) spectra. The atmospheric data were collected at a nearby meteorological station on a 10 meter tower, and averaged over 5-minute intervals. The temperature, wind speed and direction were recorded at 2 and 10 meter heights. The dew point and atmospheric pressure were also recorded. The noise and atmospheric data relevant to the events under study are summarized in Tables 1, 2 and 3.

Six noise events (Shot # = 1, 2, 4, 5, 6, and 7) were recorded at three sites. The Sound Pressure Level spectra were derived as follows (ibid p.8): "The Larson Davis Laboratories (LDL) Precision Integrating Sound Level Meter (SLM) (model 800B), with a LDL 1/2-inch condenser microphone (model 2559), was used to manually monitor the noise environment... The {attenuated} signals from the LDL SLM were recorded on a Racal Store 4DS instrumentation recorder.. with a frequency response of 0-5000 Hz. A Nicolet Scientific Corporation 660B Dual Channel FFT Analyzer.. was used to obtain the 1/3 octave spectrum of the noise" {averaged over 40 seconds}. The reference spectra for the purposes of this study were taken from the noise measurements at Site 5.

Due to various anomalies in the measured noise data, not all the available noise spectra were deemed suitable for comparison purposes. Shots 1 and 7 had data missing from either site 6 or 7. Shot #4 showed a distinct shadow zone at site 6, resulting in 25 dB Overall SPL (OASPL) attenuation. (It is possible that this phenomenon was due to local refraction of the sound waves. Sites 5, 6 and 7 laid in a line on level terrain, on top of a 70 foot high plateau, and gave rise to a possible acoustic shadow zone due to the topography and micrometeorology.)

A plot of each shot's OASPL site-to-site attenuation versus its scalar wind component (at 2m height along the array) was created (Figure 1). The attenuation due to spherical spreading for each inter-site propagation distance was calculated and used for comparison. This information was used to select optimum noise events to examine in the model comparison. Only shot #2 showed little anomalous propagation effects, that is, it most nearly approximated spherical spreading. It was chosen as a "best case" and to help establish the appropriate modeling techniques. Shot #5 was also chosen to provide a "worst case" and in keeping with the plan to analyze the loudest noise events. Shot #6 could also be studied but was considered unnecessary.

The LDL 800B allows different settings of signal attenuation prior to output to the recorder. At Sites 5 and 6 the attenuation settings were 30 dB higher than at Site 7. For Shot #2, this had no noticeable effect on the Site 5 noise spectrum; however, at Site 6 the noise floor is evident around 70 dB and at Site 7 it appears around 40 dB (Table 1). This can be seen to have a noticeable influence on the 1/3 octave band SPL difference spectra above band 34 (Figure 2). For this reason, the A-weighted Overall Sound Pressure Levels (OASLAs) used for comparison are calculated from bands 11-34, in all cases (Figures 5-10). The SPL difference spectra (Figure 3) for Shot #5 clearly show that some anomalous propagation exists, since the SPLs in bands 23-25 actually increase from Site 5 to Site 6. This problem will be discussed further in Chapter 5.

Chapter 2

COMPARISON OF OMEGA 1 MODEL PREDICTIONS

The Omega 1 model was developed by the Air Force's Armstrong Laboratory Noise Effects Branch (AL/OEBN) and is empirically based on the extensive aircraft noise propagation database collected during the Overground Excess Sound Attenuation (ESA) study (Ref 2). The ESA study includes 415 ground runup events collected over a 15 month period. The ESA measurements thus include a variety of atmospheric propagation conditions and, therefore, considerable scatter in the noise measurements at distant sites. The ESA site at 2087 meters from the source provides some insight into the amount of scatter that can be expected in noise attenuation measurements similar to those recorded in the Pershing II noise measurement survey. The standard deviation of excess attenuation at this distance for all events in the ESA study was about 10 dB, Figure 4 (Ref 3, Figure 6). This value is somewhat higher than it would be if only atmospheric propagation conditions similar to those in this study were included.

The results of the ESA study provide a substantial basis for the formulation of a noise propagation model which represents typical airbase noise propagation conditions (Omega 1). An acoustic energy-averaged propagated noise level will be mathematically biased toward the higher measured levels. Therefore, any model of excess attenuation which will predict average propagated levels must give a commensurately lower attenuation as a function of distance. The Omega model was constructed as recommended by Reference 2, Figure 21, using (roughly) a 2±1 m/s downwind propagation model. It also allows a variable effective flow resistivity, although that parameter does not enter into the propagation calculations examined here. It accounts for atmospheric absorption based on surface temperature, relative humidity and air pressure, in accordance with the Society of Automotive Engineers Aerospace Recommended Practice (SAE ARP) 866A. Ground impedance, source and receiver heights are not included in the model, but are effectively defaulted to the values typical of an aircraft engine during ground runup, propagating noise over level grassy terrain, and a standing observer.

The Shot #2 simulation predicted OASLAs which are 5 and 10 dB high at Sites 6 and 7 respectively (Figures 5 and 6). The Shot #5 simulation appears a little better since the OASLAs are 3.8 dB low at Site 6 and 6.8 dB high at Site 7 (Figures 7 and 8). The wind speed assumed by the model is higher than those recorded during the measurement study, indicating a commensurate increase in sound speed gradient.

The stronger downward refraction of sound waves will, in theory, enhance the refractive effect which mitigates attenuation. This effect is evident for Shot #2, even though the wind speeds are not very different (Table 3). The Shot #5 result is inconclusive, considering that the Site 5 reference spectrum may be misleading (Figure 3). The refractive effect will be discussed in more detail when comparing results (Chapter 5). Since there are no alternatives to the input data used, no "best fit" Omega 1 simulations could be conducted.

Chapter 3

COMPARISON OF ACOUSTIC DETECTION RANGE PREDICTION MODEL (ADRPM) PREDICTIONS. (Pre-release Version 7)

The Acoustic Detection Range Prediction Model (ADRPM) program was developed by Bolt Beranek & Newman Inc, under contract to the Army Tank Automotive Command (TACOM), for the purpose of estimating target detectability (Ref 4). It provides detailed source, receiver and propagation condition characterization via a menued input. It uses the SAE ARP 866A atmospheric absorption model and incorporates selected refractive weather conditions using predetermined ray-tracing calculations to estimate propagated noise levels. ADRPM's predictions are also force fitted to empirical data from studies of low-frequency noise propagation (Ref 5, p 17).

There are several aspects of the model parameters which must be explained to provide a fairly complete portrayal of the simulation effort. ADRPM requires that the maximum distance from the source to the reference spectrum be 500m, thus necessitating the use of a reconstructed source spectrum, force-fitted to the site #5 (790m) measured data. There are 14 possible choices of atmospheric profile, each with a default wind speed and surface temperature. Although an option exists to change temperature and humidity, the temperature is forced back to the default value during calculations for all the non-isothermal profiles.

The available atmospheric profile choices did not closely match the field measured temperature or wind speed. The Mid-Latitude Summer Day profile was a best approximation to Shot #2, whereas the Isothermal profile could be used for Shot #5. The ground impedance was characterized by the effective flow resistivity typical of a grass field. The value chosen makes no difference since the ground impedance model is shut off for distances beyond 500m (Ref 2). The "best fit" propagation conditions did not require the use of the Barrier or Foliage models which ADRPM provides. A few simulations were carried out with Barriers, to determine if this could explain anomalies in the measured noise data, such as that previously mentioned concerning Shot #5.

The ADRPM ground impedance model calculations "cease at distances greater than 500 meters from the source, on the pragmatic grounds that users are unlikely to have detailed knowledge of ground surfaces at greater distances, and that stable conditions assumed for phase-related calculations are unlikely to obtain at greater distances" (ibid, page 18). This cutoff is reasonable from an engineering standpoint since acoustic waves do become incoherent with distance. However, a step-like change in the assumed coherence of the acoustic waves is not physically realistic. The work of Wiener and Keast (Ref 15, figure 3) concludes that such scattering effects begin gradually in the upwind shadow zone. Research toward developing an analytic model of turbulent scattering in the shadow zone is ongoing (Ref 16). A proposed empirical formulation of this phenomenon is discussed further in Chapter 6.

Note the missing 1/3 octave band SPL predictions which occurred for Shot #2 at higher frequencies (Figures 5 and 6). This anomaly is due to a numerical error within the model, in the spectral propagation matrix associated with the non-isothermal profile used. The anomaly is known to be related to the source height and could not be remedied during this study.

The best ADRPM simulation for Shot #2 predicted an OASLA only 1.6 dB high at Site 6 and 6 dB high at Site 7 (Figures 5 and 6). The Isothermal (zero wind) simulation used for Shot #5 predicted an OASLA which is 6 dB low at Site 6 and 3.6 dB high at Site 7, not unlike the Omega 1 result (Figures 7 and 8). These predictions are consistent with results of the theory of atmospheric refraction. The Shot #2 simulation used the Mid-Latitude Summer Day atmosphere with a wind speed of 3.6 m/s. This profile will tend to predict higher noise levels, due to its increased downward refraction, relative to the levels seen in the actual Shot #2 atmosphere with wind speed of 1.05 m/s. Although the wind speed cited in the ADRPM model is somewhat higher than in the Omega 1 model, the predicted OASLAs are lower. This fact is interesting in that it reflects on the different approaches taken by the models.

The Omega 1 model incorporates an atmospheric sound-speed profile to the extent that it is coupled to the acoustic average of the measured propagated noise levels. The wind and temperature **gradients** are unknown, but in order to produce higher level predictions than ADRPM, they must be (on average) more strongly downward refracting. The choice of the Mid-Latitude Summer Day conditions within ADRPM does not, then, mean that the sound speed gradient being used is higher than the effective sound speed gradient of Omega 1. The predicted level differences cannot be fully explained without greater knowledge of the explicit treatment of atmospheric refraction in ADRPM.

Chapter 4

COMPARISON OF THE FAST FIELD PROGRAM (FFP) MODEL PREDICTIONS. (Version 3)

The Fast Field Program was originally developed for predicting sound propagation in the sea. It has been adapted to atmospheric propagation and further developed by the University of Illinois and the University of Mississippi under contract to the Army Construction Engineering Research Laboratories (CERL), (Ref 6). It has been validated against data collected at Bondville, Ill., for medium to low-frequency tone sources. It has demonstrated some value for long-range average noise level prediction (Ref 7). The program includes an elaborate menu of input choices, including four choices of ground impedance model and complete description of the atmospheric sound speed profile. It is a computationally intensive program developed for detailed sound propagation modeling.

The FFP analyses used the previously stated propagation distances, source and receiver heights in all simulations. In this model, some sensitivity to the effective flow resistivity was noted, with 200,000 mks Rayls/meter being the best fit for this parameter. The method recommended by Embleton, et al (Ref 8), was used to arrive at this effective flow resistivity value. The measured 1/3 octave band SPL difference spectra (Figure 2) show a distinct ground impedance effect in the appropriate 1/3 octave bands. Figures 6 and 7 show that the measured effect of this ground impedance model (absorption in bands 21-25) was much less than predicted for Shot #2 at Site 7 and for Shot #5 at Site 6. For Shot #5 at Site 7, no noticeable ground impedance effect is evident (Figure 8). Therefore, the Shot #5 simulation always used an effective flow resistivity of 2E+8 mks Rayls/meter to suppress the ground impedance model from the calculations. This approach was also tried for the Shot #2 simulation (Figures 9 and 10).

Certainly it is possible to adjust the predicted effects due to ground impedance by application and adjustment of more advanced models. Attenborough's Exponential Porosity ground impedance model was tested using the parameters derived from measured acoustic data taken at White Sands Missile Range over a short dirt range (Ref 9). The agreement with acoustic data from the PUADA site was still poor due to large impedance dips in the predicted spectra. It was concluded that ground impedance effects do diminish significantly at these long ranges, as discussed in the previous chapter. This effect is due to (distance dependant) incoherent propagation which cannot be modeled in the Fast Field Program formulation.

The atmospheric absorption model was chosen to make maximum use of the information available. The acoustic absorption coefficients for each band were determined from the relative humidity and measured temperature. The relative humidity was calculated separately, based on the measured dewpoint. The FFP program uses the ANSI S1.26-1978 standard as its source of atmospheric absorption coefficients.

The atmospheric refraction calculations are dependant on two types of menued input, the atmospheric profile (which determines the sound speed profile) and the layering method, which increases accuracy and computation time. Several variations of the atmospheric profiling/layering approach were tried. All atmospheric profiles were generated using the measured data at both the 2 and 10 meter heights (Table 3). The atmospheric profiles are required to be linear for the first height segment (up to 2m in this study), but beyond that, a logarithmic profile option may be chosen. A logarithmic interpolation to the 10m height and extrapolation to 80m was tried for both wind speed and temperature. This is consistent with meteorological theory for a neutral atmosphere (Refs 11 and 12). A preliminary comparison indicated that a totally linear temperature profile yielded a better approximation of measurements. Some improvement may also have been achieved by use of a stable atmospheric profile (Ref 13), which could not be tested in this study. In all cases, the (linear or logarithmic) fitting coefficients determined by interpolation were also used for the extrapolated segment.

The atmospheric layering was also required to be linear for the first height segment and was chosen to be logarithmic above 2m. This choice was made due to the decreasing importance of the upper layers as contributors to the predicted SPLs. The sound-speed profiles for Shots #2 and #5 were downward refracting up to around the 10m and 4m heights respectively. In this study, forty layers were created in the linear region and sixty in the logarithmic region extending to 30m height. For best accuracy, the layer thickness needs to be approximately equal to the wavelength. A test case was run in which the atmospheric layering was defined as in Reference 13 (400 layers below 100m), with only minor improvement in the resulting spectra and OASLA (Figures 12 and 13). The upper 50m of atmospheric (soundspeed) profile were usually incorporated as a single layer, since sound waves propagated to these heights added very little to the predicted noise levels. This would not be true if a temperature inversion existed at these heights.

The numerical methods used in the formulation of the FFP require that an artificial attenuation ("extra loss") be applied to broaden the peaks in the k-spectrum. A reliable approach to determining this parameter based on the source-receiver geometry and ground impedance is given in Reference 13. An artificial attenuation value of 0.0001 is accepted as a default. For this study, low-frequency FFP runs used values of 0.001 (12.5 - 80 Hz) or 0.0003 (100 - 160 Hz) to decrease computation time.

The format of the FFP's acoustic data output is not readily comparable to the measured acoustic spectrum. A file containing SPL attenuation as a function of distance is given for each of the 27 1/3 octave bands. These must first be converted into SPL attenuation spectra for each Site, then interpreted via the level difference spectrum method. The level difference spectrum method is also used (internally) in the previous models. The Site 5 measured spectrum is assumed to contain whatever effects exist in the Site 5 predicted SPL difference spectrum, since the true source spectrum is unknown. The 1/3 octave band SPL differences are applied to the Site 5 measured spectrum to derive the Site 6 and 7 predicted SPL spectra (using a spreadsheet). A VAX DIGITAL Command Language (DCL) program was devised to execute a series of FFP band center frequency runs. The DCL program also enabled the FFP output to be examined near the Site distances, and SPL attenuation spectra to be derived by application of a separate FORTRAN program named SPEC (Appendix A). The SPEC program can be rewritten to accomplish more complex analyses of the FFP output.

The best Shot #2 simulation predicted OASLAs only .1 and 1.2 dB high at Sites 6 and 7 respectively. This result tends to hide some significant errors due to the ground impedance model (Figure 6) for frequencies in the 100 - 500 Hz range. The Shot #5 simulation made noise propagation predictions similar to those of the other two models. The predicted OASLA at Site 6 was 7.1 dB low, and at Site 7 it was only .5 dB low (Figures 7 and 8). This good comparison tends to support the modeling of atmospheric effects, in spite of the apparent problems with the ground impedance model used. Since all three models had similar difficulty in modeling the Shot #5 noise measurements, a further analysis was conducted to determine if the reference Site 5 measured SPL spectrum was the source of error.

Chapter 5

COMPARISON OF METHODS AND THEIR PREDICTIONS

It is obviously difficult to validate a universally accurate prediction model, given the assumptions pertaining to the propagation conditions which are necessary in environmental noise measurement studies. The small amount of noise measurement data examined in this effort (two events) precludes any quantitative assessment on the validity of any model. Some qualitative observations are nonetheless valuable. As expected, the more complex models showed better agreement between predicted and measured levels.

The Omega 1 model provides very rapid SPL predictions in a manner which is easily applicable to the existing programs used for airbase environmental noise prediction (NOISEMAP in particular). Detailed acoustic propagation conditions, other than the atmospheric absorption parameters, are not included in the model. Such limitations may cause significant errors when detailed interpretation of specific noise level data is required. Measured noise data is often recorded after having propagated through atmospheric (sound speed profile) conditions which are significantly different from the "normal" conditions assumed by the model. The data reduction and normalization process adjusts the measurements to remove the effects of Excess Sound Attenuation (Ref 2). Under "abnormal" atmospheric conditions, this would result in an inappropriate adjustment being applied.

Furthermore, an airbase which is surrounded by hard-packed soil or desert sand will experience overground propagated noise levels that differ slightly from predictions based on the ground impedance of grassy terrain. The typical wind direction at a particular airbase location may influence its long-term average noise level contours, particularly in the upwind direction or if the downwind speed noticeably exceeds 3 m/s. The Omega 1 noise level predictions compared to measured OASLA data reasonably well in the two cases examined here partly because the measured data were collected in a moderate downwind atmosphere, which is the assumed condition incorporated in the model.

The ADRPM approach also produces rapid SPL predictions which are in good agreement with the measured SPLs. The results indicate that refractive effects do exist in the measured noise data, but the limited choices of model atmospheres don't give the capability to accurately model them. ADRPM does allow upwind or downwind propagation, but only in the 14 specific cases which have been analyzed and included in the model. The application of previously analyzed sound speed profile conditions enables rapid application of the level difference spectrum method to arrive at noise predictions. The ADRPM report file output could be reconciled with the format requirements of other (Omega series) programs with a little postprocessing. Close examination of the (Site 5 or 6) measured ground reflection effects in comparison to the predicted SPL spectra indicate that the assumption in ADRPM that ground reflection effects are negligible beyond 500m is not altogether true. These observations lead to the conclusion that ADRPM's ground impedance modeling at longer distances could be improved.

The FFP model gave very accurate SPL predictions, although at the expense of much longer computation times. It is clearly necessary to allow longer computation times if the real atmospheric profile variables are treated as variables. [Research is ongoing to reduce the computation time required by the FFP (Ref 14).] The advantages to including atmospheric profiling are thus twofold: The predicted noise levels are very accurate and are reasonable in that all relevant, accessible acoustic propagation parameters are included. The FFP approach does have a drawback relative to the needs of long-term environmental noise predictions, since only basic knowledge of the sound propagation conditions can then be assumed. Primarily, it requires input of several numerical methods parameters. In particular, it requires that the number of points used in the Fast Fourier Transform be input and is sensitive to the "extra loss" used to avoid poles in the complex plane during numerical integration. These parameters (and the atmospheric profiling/layering used) are not totally independant of the basic propagation condition variables. It therefore may be possible to automate such input, alleviating the need for the user to define the various parameters. A systematic method for accomplishing the required tasks is outlined in reference 13.

The FFP ground impedance formulation severely overestimates the magnitude of the ground reflection effects at long distances. To investigate the effects of the ground impedance model separately, an additional simulation of Shot #2 was conducted with the ground impedance suppressed (Figures 9 and 10). The simulation is similar to that used for Shot #5, with an effective flow resistivity of 2E+7 Rayls/m. It is evident that the magnitude of the attenuation maximum at 125 Hz is overpredicted by the standard Delany Bazley Chessell (DBC) ground impedance model, by comparing the result to the previous Shot #2 simulation (Figures 5 and 6). The most reasonable theoretical explanation is that the acoustic wavefronts become incoherent as they propagate through turbulent air and local temperature fluctuations. The ADRPM model assumes that the acoustic waves are coherent up to 500m, then incoherent for longer propagation distances. It is evident from the small amount of data presented here that no model accounts for this phenomena very well. These observations lead to a recommendation for further study of this effect.

It has been observed throughout this study that the Shot #5 propagated spectra reveal some anomalies, particularly in that the band 23-25 SPLs increase from Site 5 to Site 6 (Figure 3). Another diagnostic test was carried out to better understand the measurements for the purposes of this comparative study. In this test we assumed that the Site 6 measured SPL spectrum is a suitable reference spectrum. The level difference spectrum method was then applied using all three model predictions to give a predicted SPL spectrum for Site 7 (Figure 11). Under these conditions, the shapes of the predicted and measured SPL spectra are somewhat more similar. All models now overpredict the 1/3 octave band SPLs above 500 Hz. This observation implies that several assumptions inherent in the models are violated. The Pershing II missile was mounted with the rocket exhaust plume pointed upward at about a 20 degree angle. This necessarily will generate a complex acoustic directivity pattern. This pattern is influenced by the crosswind at 80 degrees relative to the propagation path in an unknowable way. The atmospheric variables were also rapidly changing at 9:07 in the morning. These factors cannot be accurately simulated based on the available knowledge of the field test atmospheric conditions.

It may be possible to deduce the effective sound-speed profile from the acoustic data, but not from the normal meteorological measurements. The acoustic spectrum is so sensitive to micro-meteorological propagation conditions that standard atmospheric measurements never give enough detail for extremely accurate site specific noise event predictions. Nonetheless, the long-term variation of long-range propagated noise levels can be modeled reasonably well as a function of standard wind and temperature measurements and existing ground conditions, particularly in the downwind direction (Ref 13).

Chapter 6

CONCLUSIONS

Although this study was limited to a small database, it provides a number of significant insights into the problems of accurate noise propagation modeling. A primary concern for environmental noise assessment purposes is to have available a relatively simplified model (in terms of the input parameters and output format), which has been demonstrated to give reasonably accurate predictions over a broad range of frequencies and propagation distances. Many valuable efforts to demonstrate such models have been undertaken over the years, with numerous results published in the public literature. Many of these efforts have resulted in computer programs which are demonstrably able to model their respective databases. Occasionally these programs are compared one to another to show relative merits; but in many cases they are empirically validated only by small, disparate, measured noise databases. The respective noise databases often include only short range measurements, or are limited to selected (low) frequencies.

Based on the foregoing comparison of the relative merits of the three models studied, it is concluded that a simply defined modeling method is necessary that includes variable atmospheric refraction effects and improved ground impedance characterization (algorithms).

RECOMMENDATIONS

A much more significant validation and/or comparison effort is warranted. Toward this end, an effort to demonstrate the utility of the Fast Field Program in comparison to a few selected samples from the AL/OEBN Overground Excess Sound Attenuation (ESA) database has been conducted (Ref 13). The results will be published to provide serious investigators the opportunity to conduct comparable studies using other models. A more comprehensive examination of the ESA database is planned.

An improved model approach which meets the necessary conditions to specify the propagation of environmental noise must eventually be developed. It should not require the user to specify numerical methods parameters, choose the ground impedance formulation, or to devise the atmospheric layering used. The input could be similar to that used in ADRPM or BASEOPS (Ref 10), but also able to simulate a source at significant altitude and allow the computation of variable atmospheric refraction effects.

Development of an improved ground impedance model is also recommended. Several selections of ground conditions are needed for various airbase environments. The reduced influence of ground impedance seen in this study (and Ref 13), particularly in the crosswind direction over long ranges, needs to be considered. It is known that turbulent scattering has a similar, but much more pronounced, effect on noise levels in the upwind direction (Ref 15). Several detailed theoretical models of turbulent effects have been proposed to account for this phenomena (Ref 16). Such computer predictions are complex, time-consuming and have not yet been proven against sufficient long-range measured (mid- to high-frequency) noise data.

It is recommended that research be undertaken to define an acoustic coherence length (D) using a proposed formulation such as:

$$Z=Z_c[\tan^{-1}(D-d)+90]/180 \quad , \qquad D=D(f)$$

Where d is the propagated distance, f is the frequency and Z the effective impedance. Such an approach could, in principle, model the slow disappearance of the ground impedance effect seen in this study and in other long-range noise databases. A single parameter (D) to characterize the measured effects of turbulence would certainly be partly dependent on the prevailing atmospheric profile. Such functional dependence must be consistent with older results (Ref 15, etc) so that the relationship is meaningful to researchers developing theoretical models of the phenomenon. Any proposed ground impedance formulation should also be validated for Air Force purposes based on the available ESA environmental noise data.

REFERENCES

1. Russell, W. Jr, and Lewis, N. Army Environmental Hygiene Agency (AEHA) Environmental Noise Study No. 52-34-0490-90, September 1989.

2. Bishop, D.E. Overground Excess Sound Attenuation (ESA): Volume 3. Application of ESA Data in NOISEFILE. AFAMRL-TR-84-017, April 1985.

3. Bishop, D.E. Overground Excess Sound Attenuation (ESA): Volume 2. Analysis of Data for Flat Grassy Terrain Conditions. AFAMRL-TR-84-017, February 1984.

4. Fidell, S., et al Development of Version 7 of an Acoustic Detection Range Prediction Model (ADRPM-7): Volume II of III - User's Manual. AMSTA-RSC Report No. 6737, October 1988.

5. Fidell, S., et al Development of Version 7 of an Acoustic Detection Range Prediction Model (ADRPM-7): Volume I of III - Technical Description. AMSTA-RSC Report No. 6737, October 1988.

6. Franke, S.J. and Swenson, G.W. Jr A Brief Tutorial on the Fast Field Program (FFP) as Applied to Sound Propagation in the Air. Applied Acoustics, Vol 27, p 203-215, 1989.

7. Raspet, R. and Wolf, R.W. Application of the Fast Field Program to the Prediction of Average Noise Levels around Sources. Applied Acoustics, Vol 27, p 217-226, 1989.

8. Embleton, T.F.W., Piercy, J.E., and Daigle G.A. Effective Flow Resistivity of Ground Surfaces Determined by Acoustical Measurements. JASA vol 74 #4, p 1239, October 1983.

9. Attenborough, K. letter to Robert Olsen. (Effective flow resistivity = 2E+7 mks rayls/m, Porosity decay coefficient = 257m in the FFP3 Exponential Porosity formulation.)

10. Lee, R.A., and Mohlman, H.T. Air Force Procedure for Predicting Aircraft Noise around Airbases: Airbase Operations Program (BASEOPS) Description. AAMRL-TR-90-012.

11. Panovsky, H.A. and Dutton, J.A. Atmospheric Turbulence Models and Methods for Engineering Applications, John Wiley and Sons, New York, 1984.

12. Obukhov, A.M. Turbulence in an Atmosphere with a Non-Uniform Temperature: Turbulence in a Refractive Medium, SPIE Optical Engineering Press, p 278-299, 1990.

13. Raspet, R. et al Atmospheric Refraction of Noise, AL-TR-1991-XXX, to be published.

14. West, M. and Sack, R.A. New Correction Procedures for the Fast Field Program which Extend it's Range, Proceedings of the Fourth International Symposium on Long Range Sound Propagation, NASA CP-3101, p 301, May 1990.

15. Wiener, F.M. and Keast, D.N. Experimental Study of the Propagation of Sound over Ground. JASA Vol 31 #6, p 724, June 1959.

16. McBride, W.E., Bass, H.E., Raspet, R. and Gilbert, K.E. Scattering of Sound by Atmospheric Turbulence: Predictions in a Refractive Shadow Zone. Proceedings of the Fourth International Symposium on Long Range Sound Propagation, NASA CP-3101, p 245, May 1990.

TABLE 1: Shot #2 1/3 Octave Band SPL spectra
Persinng II second stage rocket motor elimination,
13 Sept 1989, 16:47 hours

Band # (dB)	Frequency (Hz)	Flat-weighted Sound Pressure Levels		
		Site 5	Site 6	Site 7
11	12.5	73.2	70.7	61.2
12	16.0	76.5	71.6	66.0
13	20.0	78.4	74.4	68.9
14	25.0	81.9	76.4	69.4
15	31.5	82.4	79.4	70.7
16	40.0	83.3	79.6	72.9
17	50.0	85.4	79.0	74.1
18	63.0	86.1	79.9	73.8
19	80.0	87.2	77.4	71.3
20	100.0	89.1	72.9	68.9
21	125.0	87.7	66.7	63.5
22	160.0	84.0	69.6	61.9
23	200.0	81.2	73.1	61.9
24	250.0	79.0	68.2	62.5
25	315.0	79.9	73.7	61.4
26	400.0	80.6	72.1	60.8
27	500.0	77.8	69.8	63.1
28	630.0	81.2	68.0	58.7
29	800.0	82.2	67.8	56.9
30	1000.0	84.3	65.7	56.0
31	1250.0	83.7	68.7	53.3
32	1600.0	82.0	69.3	50.2
33	2000.0	79.3	64.9	44.8
34	2500.0	78.9	67.4	42.6
35	3150.0	78.7	69.4	43.0
36	4000.0	79.8	75.5	44.5
37	5000.0	76.9	72.4	41.8

TABLE 2: Shot #5 1/3 Octave Band SPL spectra
Pershing II second stage rocket motor elimination,
14 Sept 1989, 09:07 hours

Band #	Frequency (Hz)	Flat-weighted Sound Pressure Levels (dB)		
		Site 5	Site 6	Site 7
11	12.5	89.6	77.6	75.1
12	16.0	91.6	82.2	76.6
13	20.0	89.8	84.6	77.5
14	25.0	92.6	87.5	78.9
15	31.5	95.0	91.3	80.8
16	40.0	96.0	92.3	81.8
17	50.0	96.5	94.4	80.9
18	63.0	96.2	94.3	79.7
19	80.0	97.4	93.1	79.1
20	100.0	98.6	89.4	77.9
21	125.0	97.3	87.0	79.0
22	160.0	93.0	91.6	82.8
23	200.0	90.6	94.3	80.0
24	250.0	87.7	92.0	81.1
25	315.0	89.9	90.8	81.3
26	400.0	96.0	91.6	80.7
27	500.0	93.1	90.8	78.6
28	630.0	97.3	94.2	73.3
29	800.0	91.6	93.4	68.1
30	1000.0	93.9	89.9	65.3
31	1250.0	95.2	87.3	62.8
32	1600.0	90.9	85.2	60.5
33	2000.0	89.7	81.2	53.4
34	2500.0	86.8	76.1	45.4
35	3150.0	83.2	72.4	40.9
36	4000.0	81.1	75.8	42.3
37	5000.0	80.0	72.8	40.6

TABLE 3: Atmospheric data (5 minute averages)

	Shot #2 9/13/89 Event at 16:47 MDT Data ave 15:45 MST	Shot #5 9/14/89 Event at 9:07 MDT Data ave 8:05 MST
(2 meters)		
Wind Speed	4 MPH	3 MPH
Direction	216 deg	347 deg
Along Array	1.05 m/s	0.23 m/s
Temperature	10.9 C, 51.6 F	10.4 C, 50.7 F
(10 meters)		
Wind Speed	5 MPH	5 MPH
Direction	219 deg	350 deg
Along Array	1.41 m/s	0.39 m/s
Temperature	10.6 C, 51.1 F	10.1 C, 50.2 F
Dewpoint	3.7 C, 38.7 F	5.6 C, 42.1 F
Rel. Humidity	62 %	74 %
Pressure	862.1 mb	935.3 mb

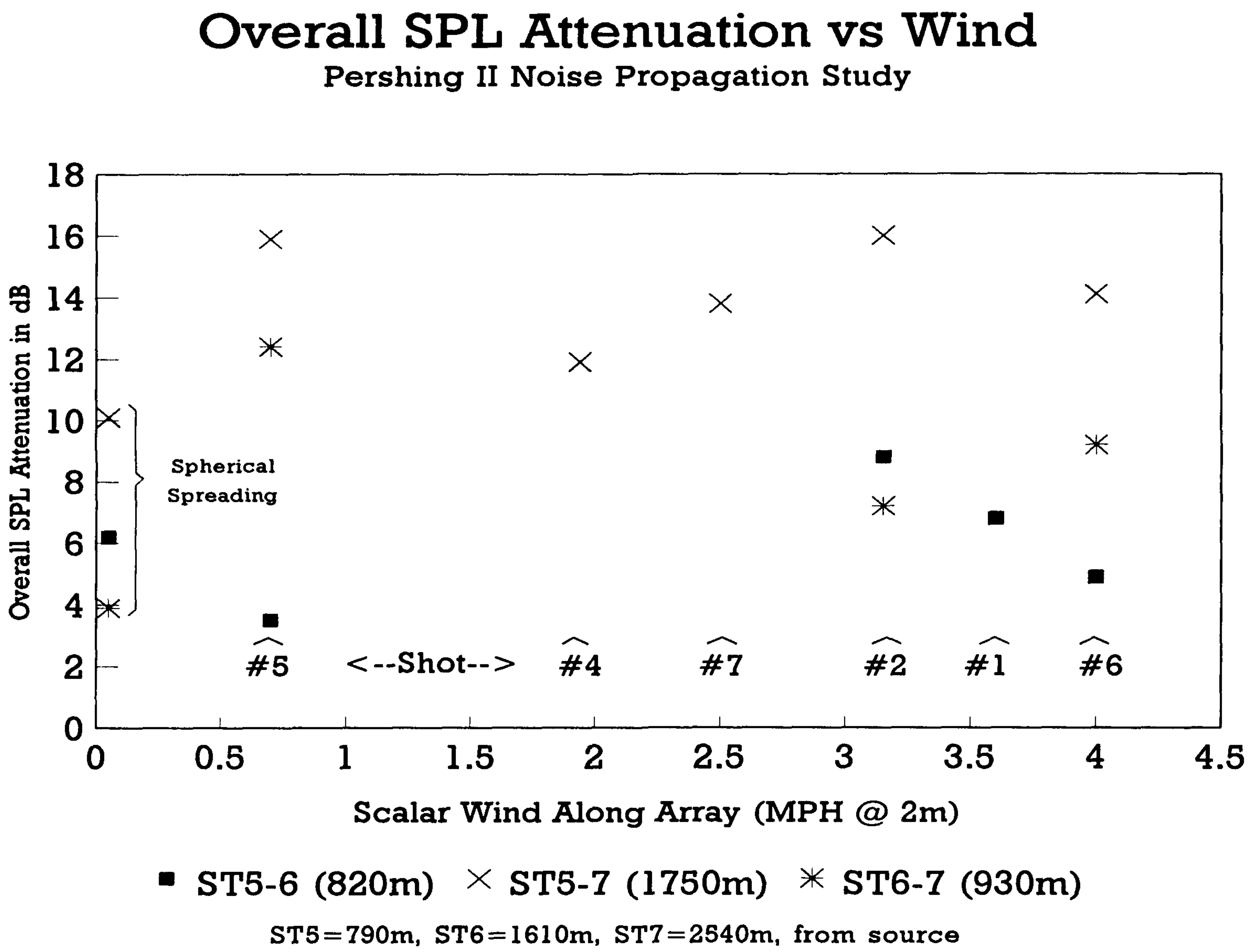

Overall SPL Attenuation vs Wind
Pershing II Noise Propagation Study
Overall SPL Attenuation in dB
18
16
14
12
10
8
6
4
2
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
Scalar Wind Along Array (MPH @ 2m)
Spherical Spreading
#5
<--Shot-->
#4
#7
#2
#1
#6
■ ST5-6 (820m)
× ST5-7 (1750m)
✳ ST6-7 (930m)
ST5=790m, ST6=1610m, ST7=2540m, from source

Figure 1

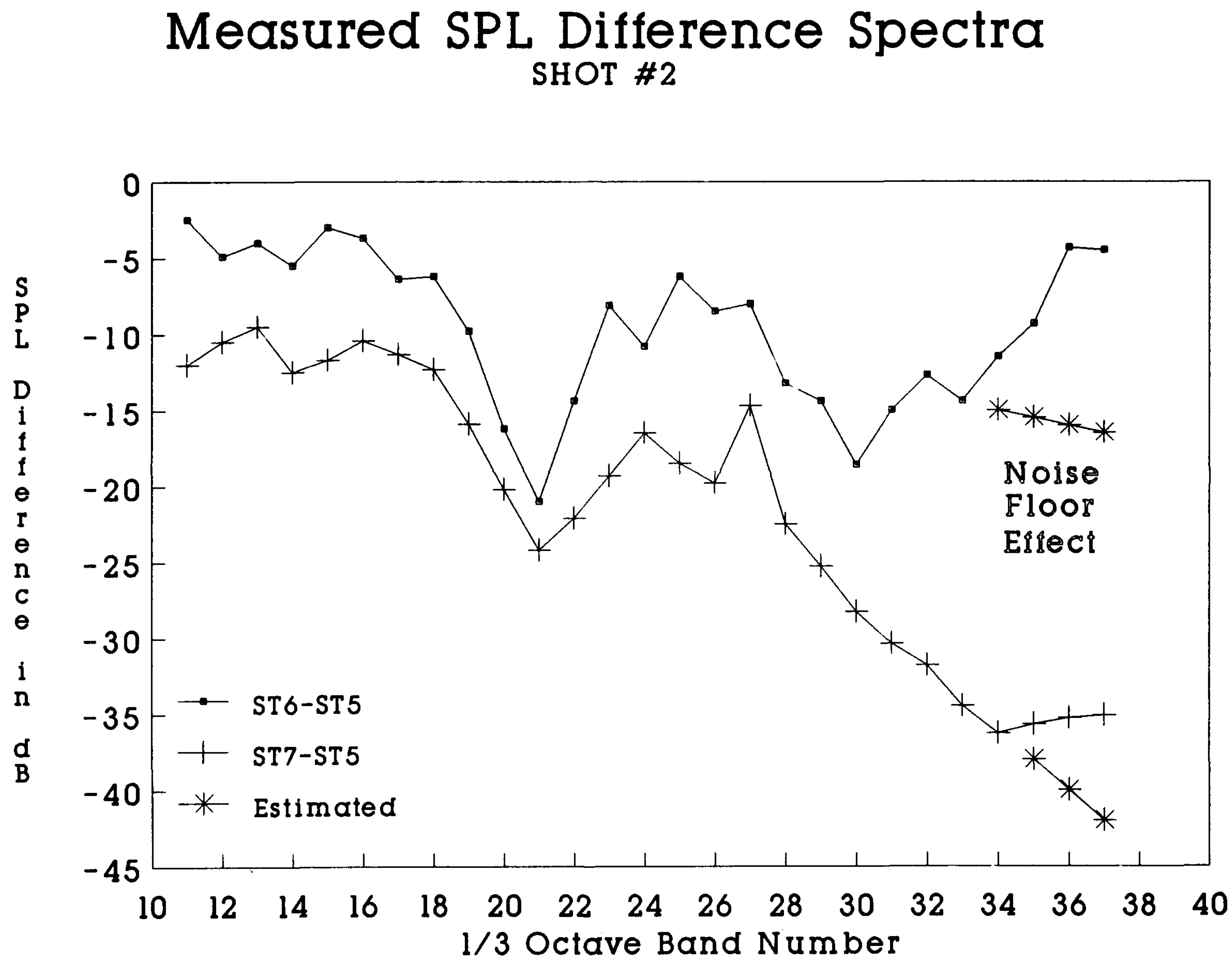

Measured SPL Difference Spectra
SHOT #2
SPL Difference in dB
0
-5
-10
-15
-20
-25
-30
-35
-40
-45
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
40
1/3 Octave Band Number
ST6-ST5
ST7-ST5
Estimated
Noise
Floor
Effect

Figure 2

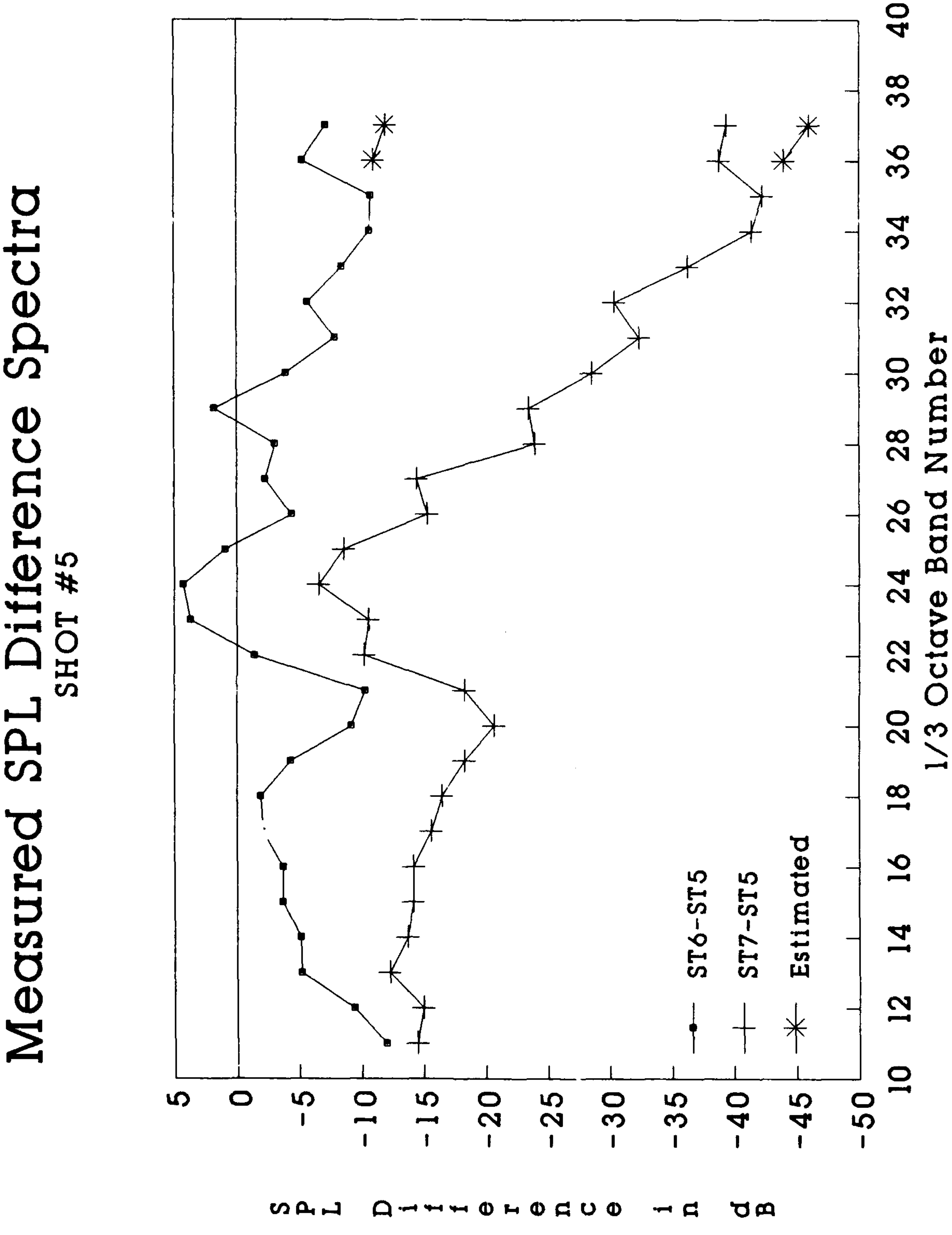
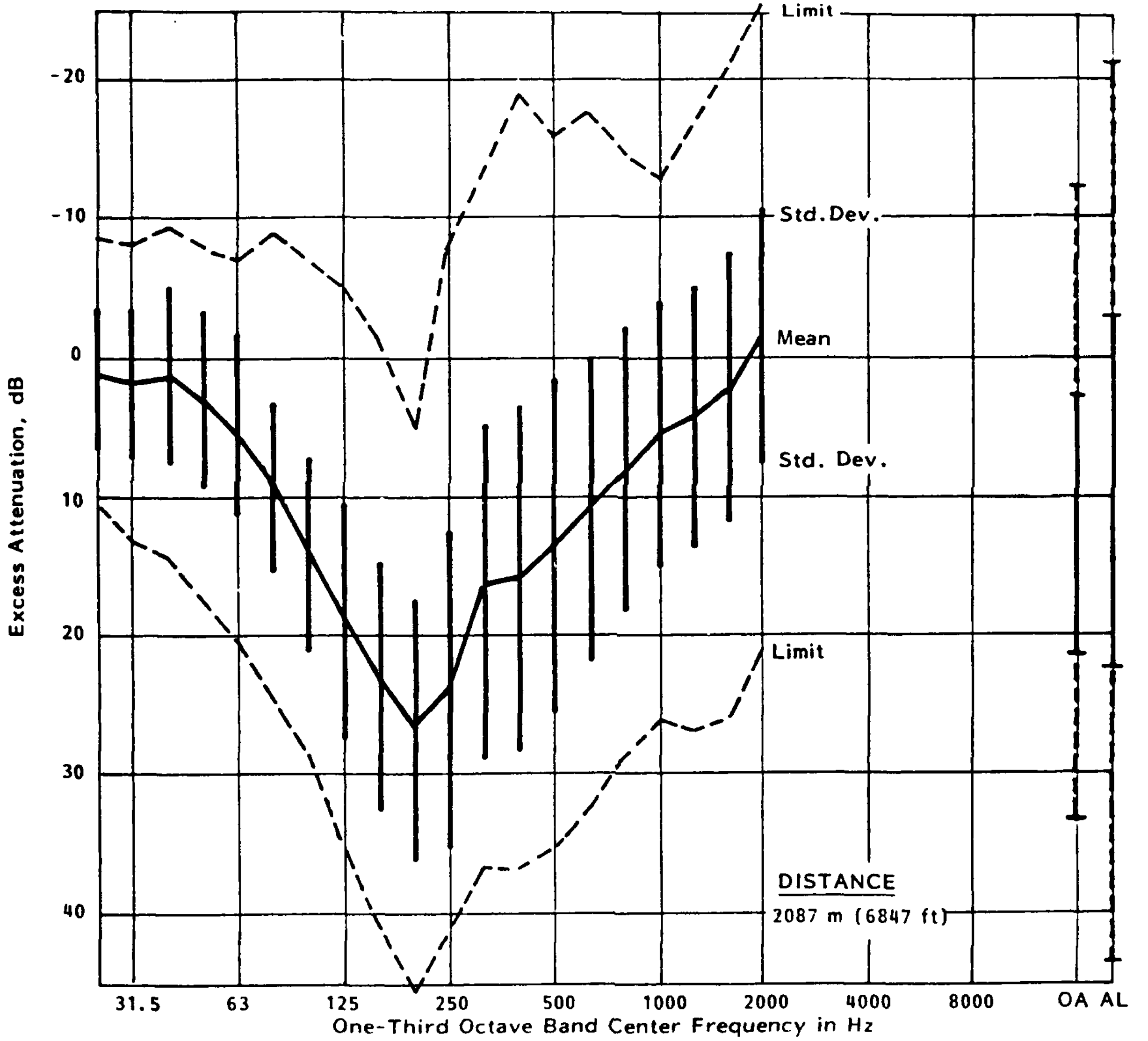

Measured SPL Difference Spectra
SHOT #5
SPL Difference in dB
5
0
-5
-10
-15
-20
-25
-30
-35
-40
-45
-50
1/3 Octave Band Number
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
40
ST6-ST5
ST7-ST5
Estimated

Figure 3



MEANS, STANDARD DEVIATIONS, RANGES OF MEASURED EXCESS ATTENUATION VALUES

Standard Deviation of Measured ESA Values, 2087m

Figure 4

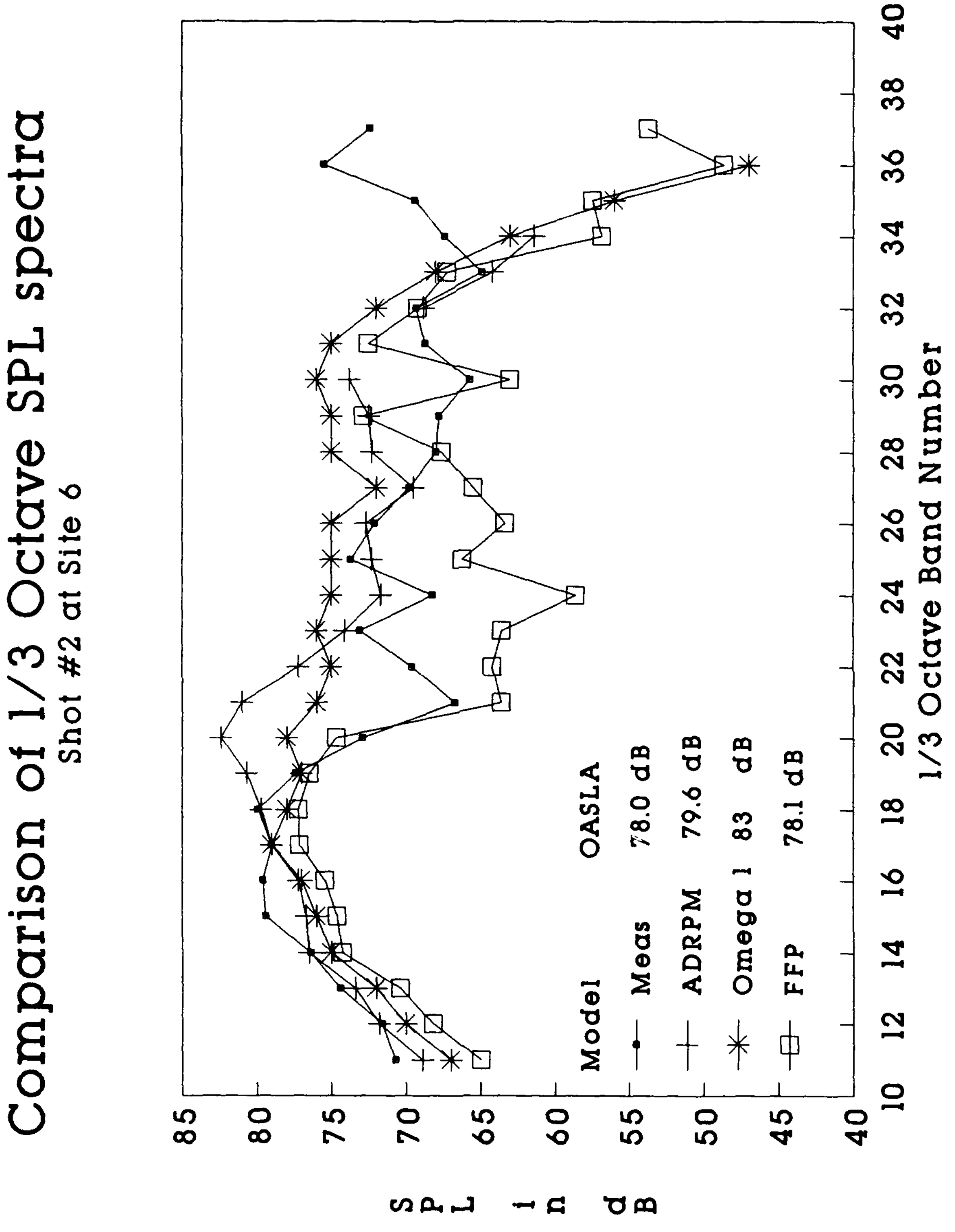

Comparison of 1/3 Octave SPL spectra
Shot #2 at Site 6
SPL in dB
85
80
75
70
65
60
55
50
45
40
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
40
1/3 Octave Band Number
Model
OASLA
Meas
78.0 dB
ADRPM
79.6 dB
Omega 1
83 dB
FFP
78.1 dB

Figure 5

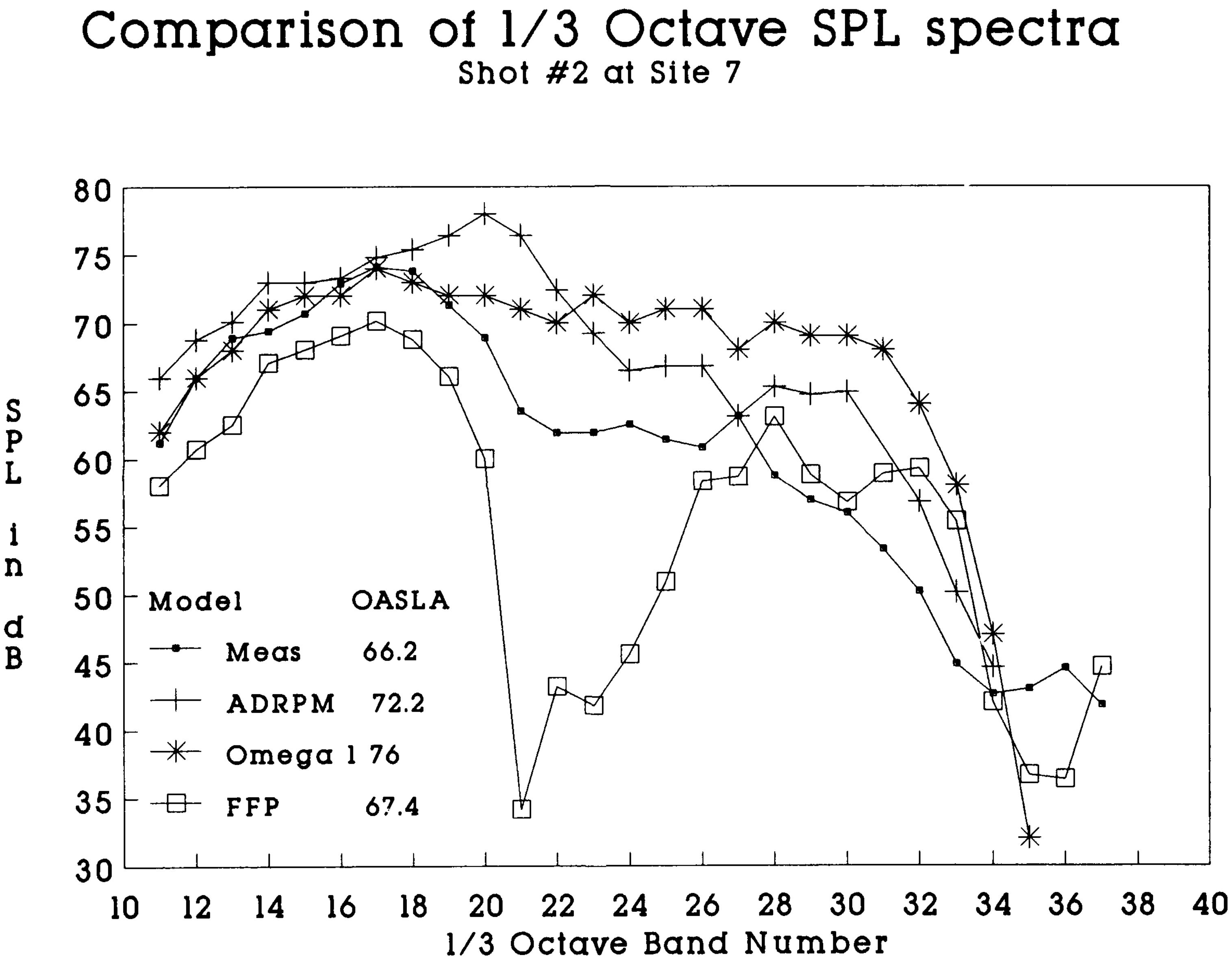

Comparison of 1/3 Octave SPL spectra
Shot #2 at Site 7
SPL in dB
80
75
70
65
60
55
50
45
40
35
30
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
40
1/3 Octave Band Number
Model
OASLA
Meas 66.2
ADRPM 72.2
Omega 1 76
FFP 67.4

Figure 6

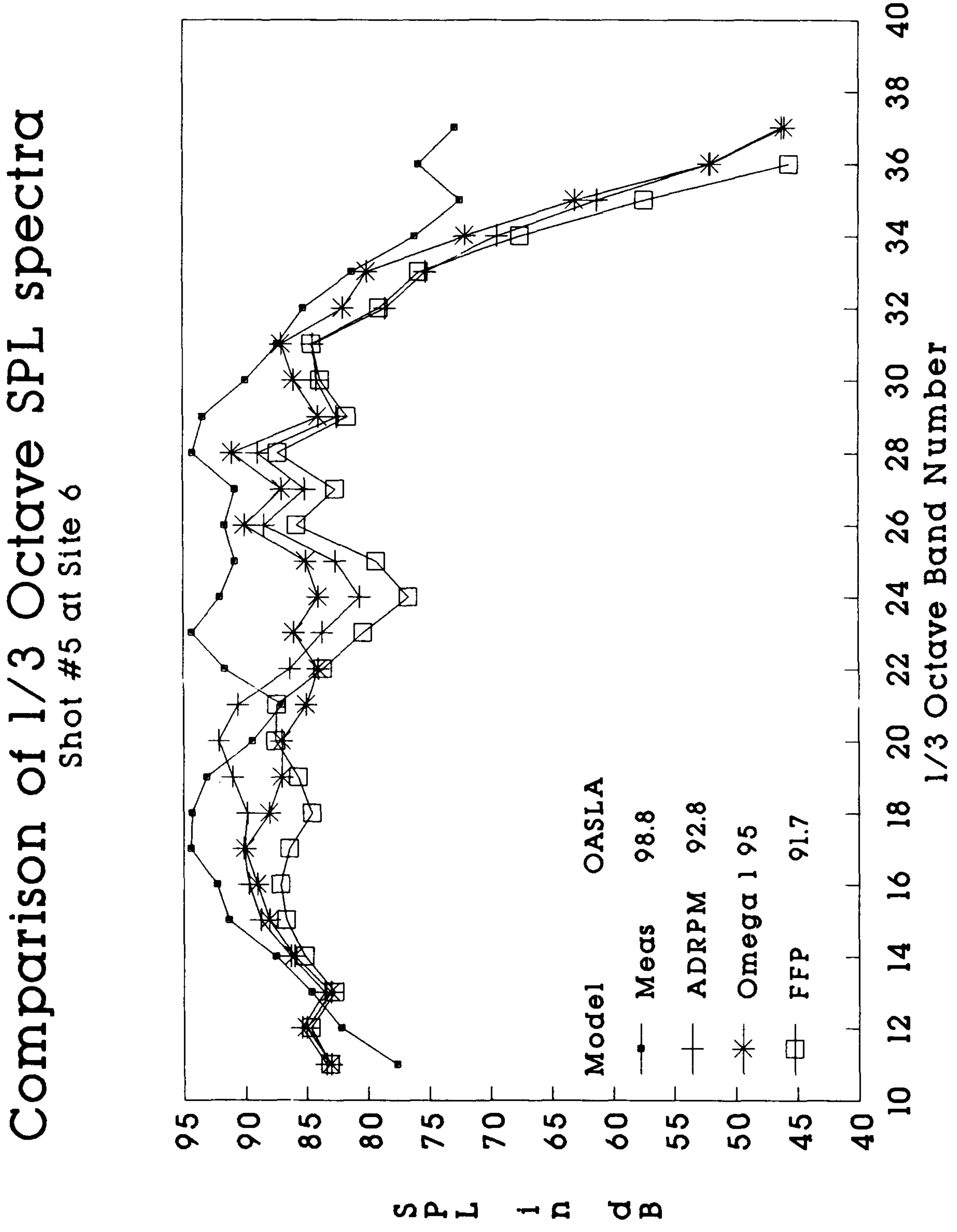

Comparison of 1/3 Octave SPL spectra
Shot #5 at Site 6
Model OASLA
Meas 98.8
ADRPM 92.8
Omega 1 95
FFP 91.7
SPL in dB
95
90
85
80
75
70
65
60
55
50
45
40
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
40
1/3 Octave Band Number

Figure 7

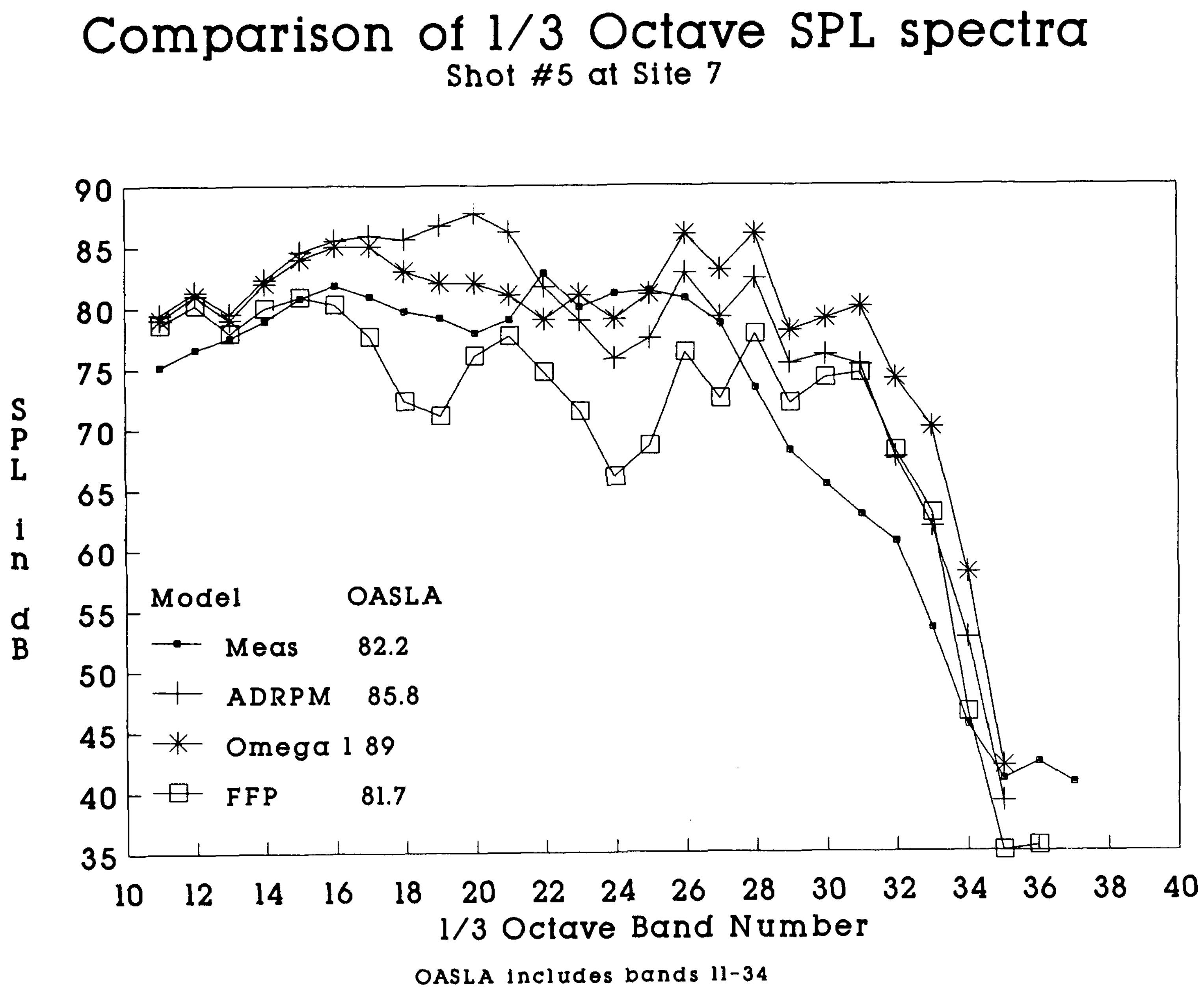
Comparison of 1/3 Octave SPL spectra
Shot #5 at Site 7
SPL in dB
90
85
80
75
70
65
60
55
50
45
40
35
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
40
1/3 Octave Band Number
Model
OASLA
Meas 82.2
ADRPM 85.8
Omega 1 89
FFP 81.7
OASLA includes bands 11-34

Figure 8

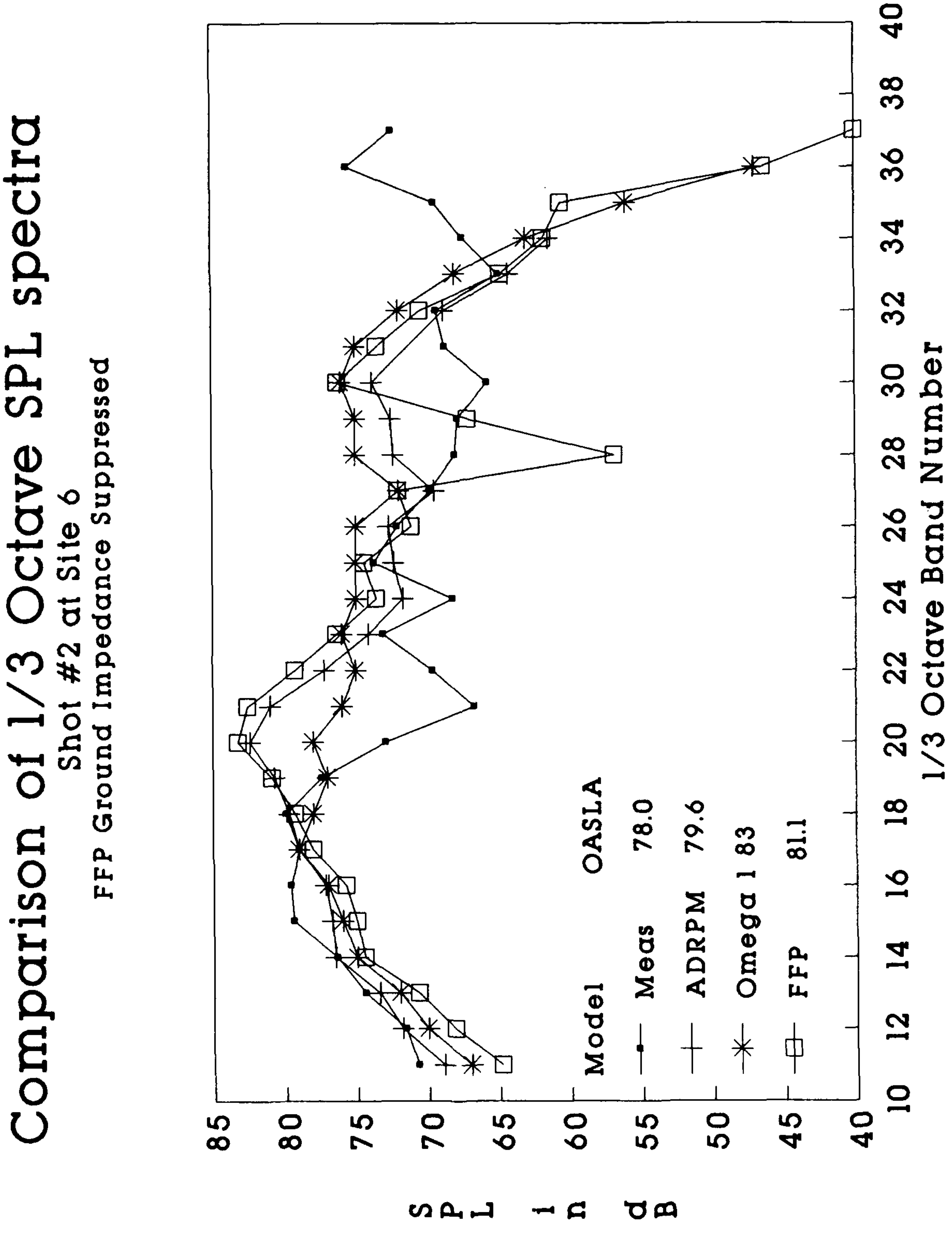

Comparison of 1/3 Octave SPL spectra
Shot #2 at Site 6
FFP Ground Impedance Suppressed
Model
OASLA
Meas
78.0
ADRPM
79.6
Omega 1
83
FFP
81.1
85
80
75
70
65
60
55
50
45
40
SPL in dB
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
40
1/3 Octave Band Number

Figure 9

Comparison of 1/3 Octave SPL spectra

Shot #2 at Site 7

FFP Ground Impedance Suppressed

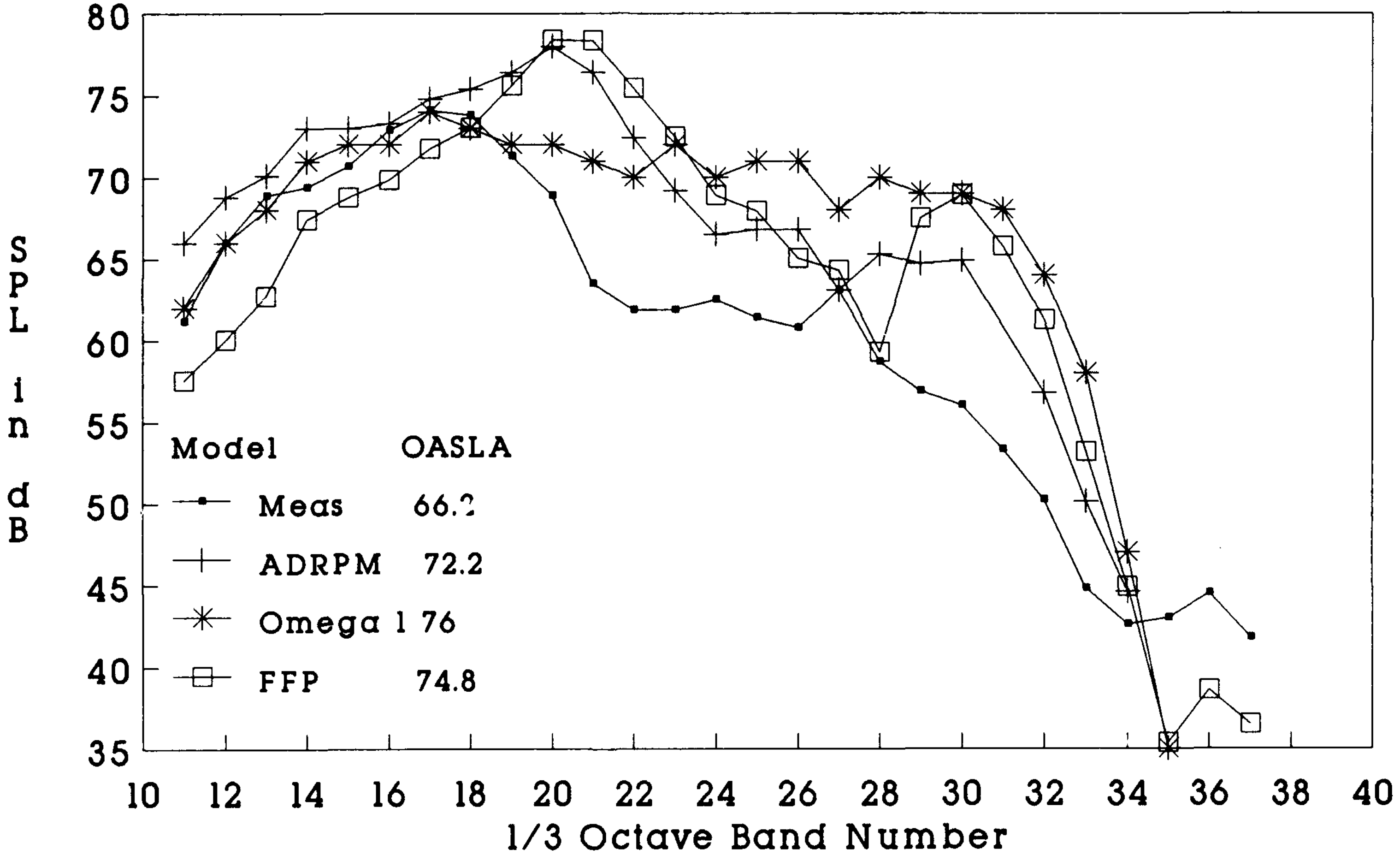
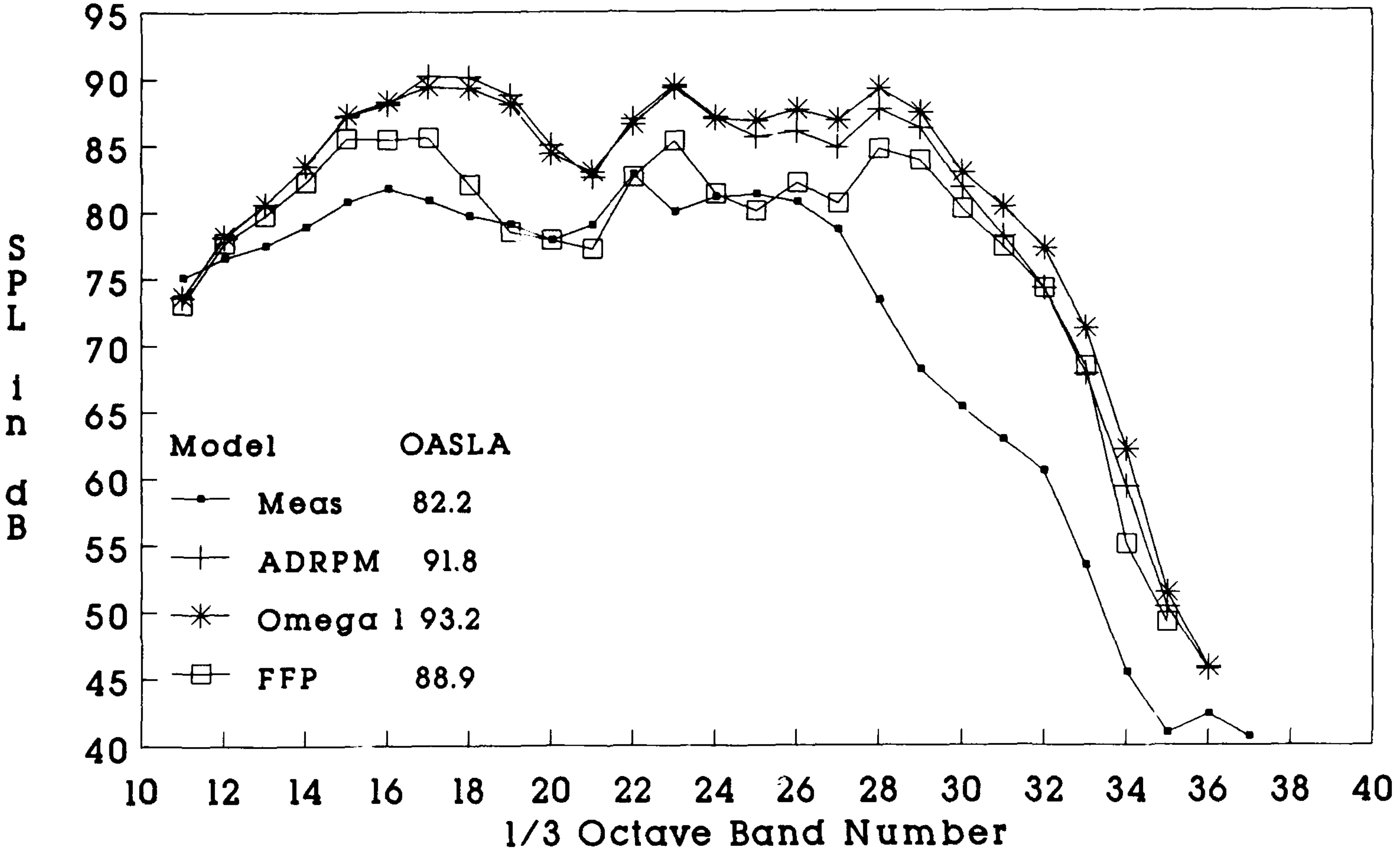


Figure 10



Comparison of 1/3 Octave SPL spectra

Shot #5 at Site 7

Referenced to Spectrum from Site 6

Figure 11

Comparison of 1/3 Octave SPL spectra

Shot #2 at Site 6

Using Fine Layering and Fixed Extra Loss

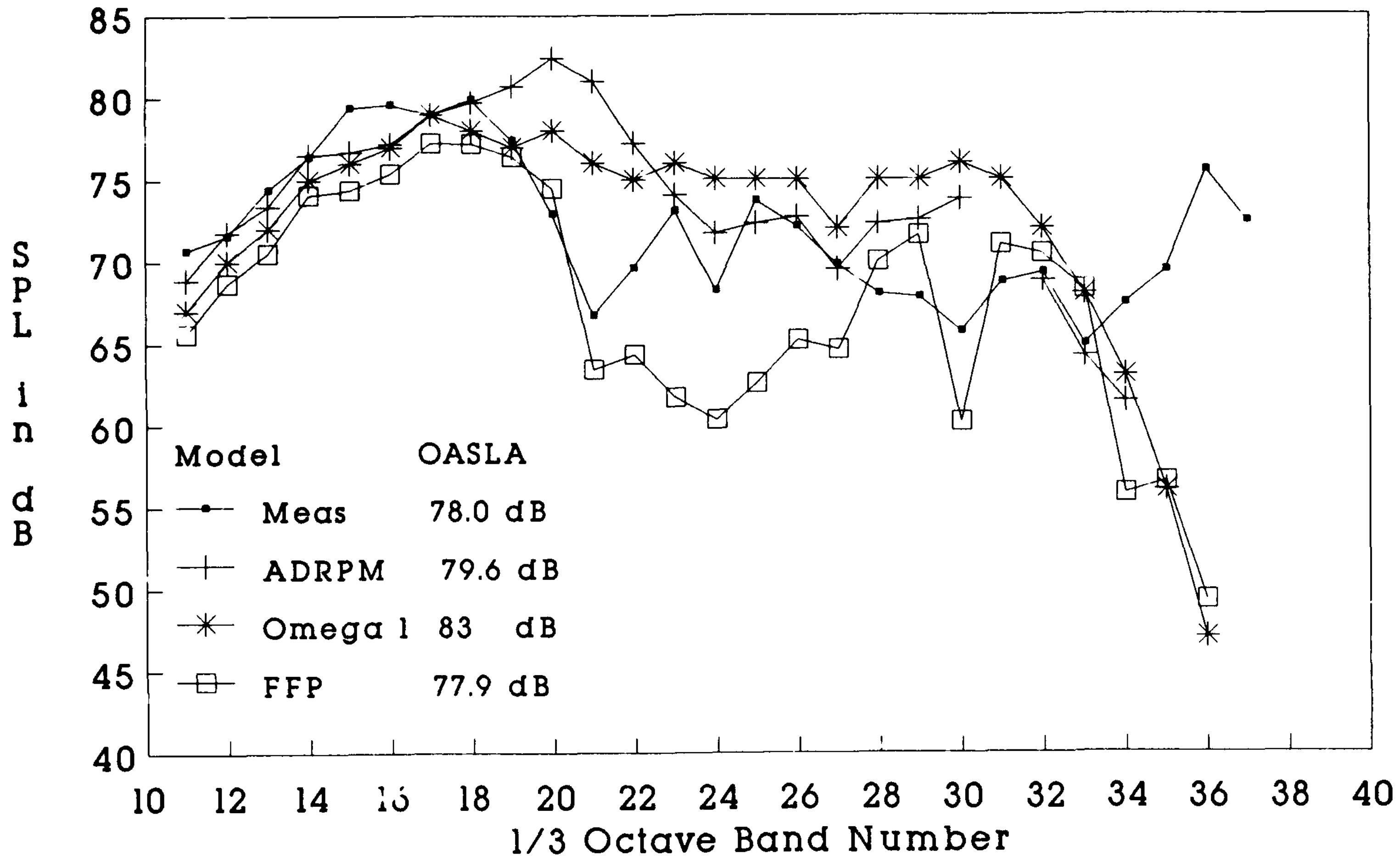


Figure 12

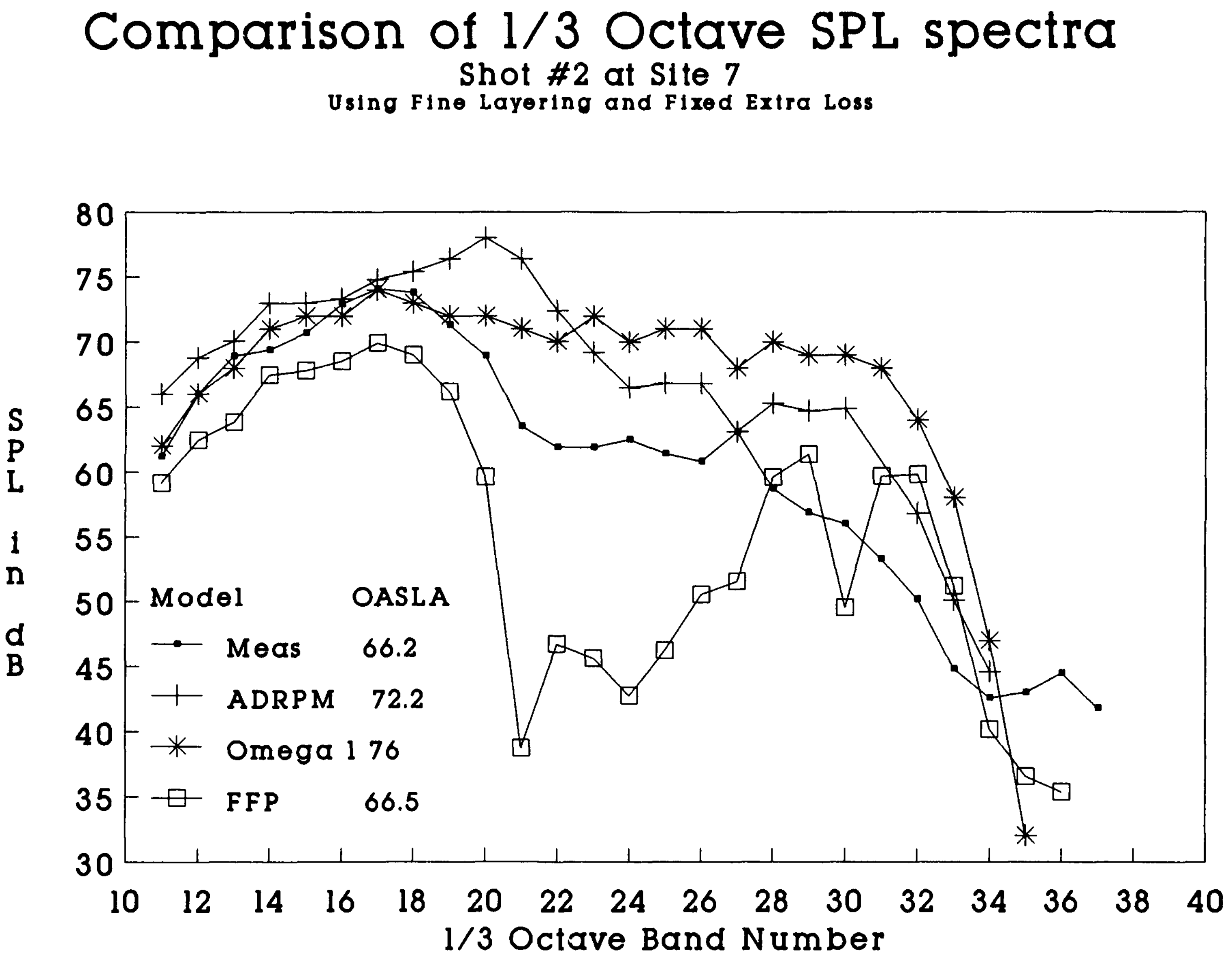

Comparison of 1/3 Octave SPL spectra
Shot #2 at Site 7
Using Fine Layering and Fixed Extra Loss
SPL in dB
80
75
70
65
60
55
50
45
40
35
30
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
40
1/3 Octave Band Number
Model
OASLA
Meas 66.2
ADRPM 72.2
Omega 1 76
FFP 66.5

Figure 13

APPENDIX A

```
$! DCL Program for running FFP3 program on all input
$! (*##.DAT, where ## is the band number) files contained
$! in the .input subdirectory.  Output is directed to the
$! .ffpout subdirectory.  The program currently drives the
$! SPEC program upon completion of each FFP3 run, but could
$! be revised to process a group of FFP3 output (*##.lev)
$! files.
$loop:
$ ffinp = f$search("[.input]*.dat;")
$ if ffinp .eqs. "" then goto done
$ p1 = f$parse(ffinp,,,"NAME")
$ band = p1
$ band[0,f$length(p1)-2] := " "
$ band = f$edit(band,"TRIM")
$ runx = p1 - band
$ call run_band 'p1' 'band'
$ goto loop
$done:
$ ren [.ffpout]sp.* [.ffpout]'runx'sp.*
$ exit
$
$run_band:
$ subroutine
$ assign/user_mode [.input]'p1' sys$input
$ run ffp3
$ ren levels.o [.ffpout]'band'.lev
$ ren wavnum.o [.ffpout]'p1'.wav
$ assign/user_mode [.ffpout]'band'.lev FOR010
$ run spec
$ ren [.ffpout]'band'.lev [.ffpout]'p1'.lev
$ ren [.input]'p1'.dat [.ffpout]'p1'.dat
$ exit
$ endsubroutine
```

```
      PROGRAM SPEC
C
C     Converts FFP level-vs-distance output files (levels.o)
C      into a level difference spectrum at sites specified
C      by data in file sites.dat
C
      CHARACTER*36  fname
      CHARACTER*30   FIL
      CHARACTER*2   BAND
      INTEGER       N, M
      REAL          DIS
      DIMENSION     DIS(15)
C
C      Reads site distances and counts the number of sites
      OPEN (9, FILE = '[.input]SITES.INP', STATUS='OLD')
      DO 6 , N=1,15
 6    READ (9,*,END=7) DIS(N)
 7    M=N-1
      DO 9 , N=1,M
C      Converts the index to an ASCII number.
      FIL='[.ffpout]sp.S'//CHAR(N+48)
C      Uses M files for generating site Atten. spectra.
      OPEN (10+N, FILE=FIL, STATUS='UNKNOWN',
     >CARRIAGECONTROL= 'LIST')
 8    READ (10+N,*,END=9)
      GOTO 8
 9    BACKSPACE (10+N)
C      Opens the current levels.o file and selects Atten.
C      data at the specified distances.
      OPEN (10, STATUS='OLD')
      INQUIRE (10, NAME=fname, ERR=21)
      BAND=FNAME(INDEX(fname,']')+1:2)
      DO 15 N=1,M
 10   READ (10,11,END=19) Dist, Ref_l, Atten
 11   FORMAT (3F15.0)
      IF (Dist .GE. DIS(N)) THEN
C      Select data nearest to DIS(N) and append band #
C      and other data to each site file, in turn.
         BACKSPACE (10)
         BACKSPACE (10)
         READ (10,11) D_less, R_less, A_less
         IF ( D_less .EQ. Dist ) GOTO 22
         IF ( DIS(N)-D_less .GE. Dist-DIS(N) ) THEN
            WRITE (10+N,*) BAND, '  ',Dist, '  ',Atten
            GOTO 15
         ELSE
            WRITE (10+N,*) BAND, '  ',D_less, '  ',A_less
            GOTO 15
         ENDIF
      ENDIF
      GOTO 10
C      Next site
```

```
 15   READ (10,*)
C      Close all site files prior to next run.
 19   DO 20 N=1,M
 20   ENDFILE (10+N)
      GOTO 25
 21   WRITE (11,*)
     >'I/O ERROR, is levels.o ASSIGNED to FOR010?'
      GOTO 25
 22   WRITE (11,*)
     >'Nearest predicted level is further than first site.'
 25   STOP
      END
```

☆U.S. Government Printing Office: 1992 – 648-069/60223