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LONG-RANGE SOUND PROPAGATION – A REVIEW OF SOME EXPERIMENTAL DATA

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SUMMARY

Three experimental studies of long range sound propagation carried out or sponsored in the past by NASA are briefly reviewed to provide a partial prospective for some of the analytical studies presented in this symposium. The three studies reviewed cover (1) a unique test of two large rocket engines conducted in such a way as to provide an indication of possible atmospheric scattering loss from a large low-frequency directive sound source, (2) a year-long measurement of low frequency sound propagation which clearly demonstrated the dominant influence of the vertical gradient in the vector sound velocity towards the receiver in defining excess sound attenuation due to refraction, and (3), a series of excess ground attenuation measurements over grass and asphalt surfaces replicated several times under very similar inversion weather conditions.

INTRODUCTION

Experimental data on long range sound propagation sound from three unique programs carried out over the last 25 years that were conducted or sponsored by NASA can provide a useful background for some of the analytical models treated in this symposium. These measurement programs are very briefly reviewed here to insure that the existence of these data may be more widely known to researchers in the field of long range sound propagation. The sources of the data are identified for the reader who may wish to pursue the information in more detail.

EXPERIMENTAL DATA ON PROPAGATION OF LOW FREQUENCY ROCKET NOISE AT LONG RANGES.

On March 24, 1964 at approximately 1340 CST, the NASA George C. Marshall Space Flight Center, in Huntsville, Alabama conducted a static test firing of a Saturn S-I first stage rocket booster on a test stand for which the deflected exhaust blast was directed due north. This rocket consists of a cluster of eight engines with a total thrust of about 1.5 million lbs. Seven minutes later, a static test of a Saturn F-I rocket engine (a single chamber rocket engine with the same total thrust), was conducted on the same basic test stand but with the deflected exhaust blast directed due south. Major results of acoustic measurements conducted out to a distance of 15 Km along a line of microphone stations on a 45° azimuth line from the test stand towards the city of Huntsville, as shown in Figure 1, were reported by Tedrick.[1] However, most of the detailed results presented here are contained in an internal NASA Memo.[2] Also shown in Figure 1 are the vertical sound velocity profiles measured in this direction at the time of each test firing and the resulting calculated sound ray paths in this same direction. The sound velocity profiles differ slightly in the first 2 Km but the resulting ray paths differ significantly. Based on a comparison of the ray paths for the two firings, one would expect to see a greater refraction loss for the second test due to the greater upward refraction of the sound ray for this test. As will be shown, precisely the opposite condition prevailed.

Not shown here are the same type of sound profiles and ray paths for a 226° azimuth direction – essentially 180° from those shown in Figure 1. The results were very similar – minor differences in sound profiles and a ray path for the second test showing more upward refraction in this direction than for the first test – again suggesting a greater refraction loss for the second test.

Although the two rocket boosters have a very different geometry, the resultant total sound power levels and spectra are very similar[1] and, as shown in Figure 2, the directivities for the overall sound pressure level at a distance of 1000 ft from the engines are very similar when the different direction of the exhaust blast for the two tests is recognized. In the direction of the microphone positions, the overall sound levels of the two rocket engines differ by about 12 dB at a 1000 ft radius. Figure 3 shows the values of excess attenuation in octave bands, including any air absorption, for the S-I test, as a function of octave band center frequency with distance as a parameter. It was convenient, for this plot, to use 1.6 Km as a reference distance for evaluating excess attenuation. The data show, roughly, the expected trend of increasing excess attenuation with distance and frequency. Figure 4 shows the same data for the S-I test re-plotted as a function of distance where the values of excess attenuation have been averaged over pairs of adjacent octave bands to simplify the data presentation. Figure 5 shows the same information for the F-I test.

However, it is not the purpose of this review to examine the <u>absolute</u> values for the excess attenuation for each test but rather examine the <u>difference</u> in excess attenuation between the two tests. This is shown in Figure 6 in terms of the excess attenuation for the S-I test (i.e., maximum lobe of noise along the measurement direction towards Huntsville) minus the excess attenuation <u>along the same line</u>, for the F-I test (i.e., maximum lobe of noise in opposite direction).

The excess attenuation along this same path <u>decreased</u> between the two tests, conducted only 7 minutes apart. This decrease is most significant for a distance of 9 Km and is more dependent upon frequency at this distance than at any other point. This <u>decrease</u> in excess attenuation could be attributed to a change in sound refraction between the two tests. However, as suggested by the sound velocity profiles and calculated ray paths in Figure 1, this effect would have been expected to be just the opposite from what was observed – i.e., an <u>increase</u> in excess attenuation due to the expected increase in refraction loss for the second test. An alternative hypothesis is that the decrease in excess attenuation could be attributed to the effect of scattering by atmospheric turbulence. This scattering would tend to increase the apparent excess attenuation in the measurement direction for the first test (i.e., remove energy from the main sound lobe in this direction) and decrease the excess attenuation for the second test by adding back-scattered energy to the weaker lobe in this direction.

This hypothesis, admittedly not proven, is consistent with the observations and with theoretical predictions.[3,4] Further research is needed to more fully evaluate and experimentally validate sound attenuation by atmospheric turbulence. Practical applications include definition of correct excess attenuation models for the directive sound fields of jet aircraft and long range warning sirens.

LONG-TERM MEASUREMENT OF EXCESS ATTENUATION WITH REFRACTION

The second sound attenuation program was conducted at the NASA Mississippi Test Range over a one year period by Tedrick and Polly.[5] The program utilized the pure tone siren/horn sound source system shown in Figure 7 mounted on a 60 ft. tower to propagate pure tone signals at 40, 80, 120 and 160 Hz at distances up to 3 Km over a flat terrain heavily covered with a deciduous rain forest. Over 29,000 excess attenuation measurements were made over the one year test period. The results were correlated with the vertical gradient of vector sound velocity from the source to the receiver as measured over the first 300 meters above the ground. Typical results for two distances are shown in Figure 8 in terms of the excess attenuation at 160 Hz as a function of this sound velocity gradient. As for all of the frequencies and distances measured, the data collapsed in the form illustrated. At any given frequency and distance, the mean excess attenuation was essentially constant when the sound velocity gradient was equal to, or greater than zero and decreased approximately linearly as the gradient decreased below zero.

The mean excess attenuation, A_0 for sound velocity gradients equal or greater than zero varied linearly with distance and systematically with frequency as shown on Figure 9 which is taken from Ref. 5. Although the excess attenuation includes air absorption, the latter is a relatively small part of the observed excess attenuation which is believed to be predominantly ground attenuation. Note that the intercept value of A_0 for zero distance is roughly proportional to frequency but the rate of increase with distance increases only slightly with frequency.

For negative sound velocity gradients, Tedrick and Polly showed that the slope of the plot of excess attenuation versus sound velocity gradient increased linearly with distance and approximately linearly with frequency (see Figure 10).

While the above presents a very simplified definition of the data trends, it has substantial face validity on the basis of the very large number of measurements involved and should provide useful benchmarks for comparison with the latest theoretical models for ground attenuation in the presence of refraction.

Another result from this long term test program was the determination of the statistical distribution in the magnitude of focusing amplification (i.e., excess attenuation which is positive) corresponding to sound attenuation less than inverse square spreading loss. While very likely a site-specific statistic, the distribution data shown in Figure 11, developed from tabular data in Ref. 5, shows that this focusing anomaly increases with distance for values of the anomaly less than about 15 dB. Note that in this case, the data cover a much longer propagation range and indicate that, on rare occasions, anomalous increases in level above that predicted by spherical spreading loss of up to 30 dB were observed.

GROUND ATTENUATION MEASUREMENTS FOR INVERSION CONDITIONS OVER GRASS AND ASPHALT SURFACES.

The final test program mentioned here was sponsored by NASA and is fully described in Ref. 6. Copies of the full report may be available through NASA, Langley. The program involved the measurement of ground attenuation over asphalt and grass surfaces on, or next to, an aircraft runway at NASA's Wallops Island facility. The tests were conducted with an elevated loudspeaker source located at 2.5, 5, and 10 meters above each of the surfaces. For most of the tests, the weather conditions corresponded to a mild inversion condition that was replicated several times for each measurement source elevation/ground surface condition. The basic test geometry and microphone array employed is illustrated in Figure 12. Note that at one distance (225 meters), microphones were located essentially at the ground surface, and at 1.2 and 10 meters. At 450 meters, microphones were located at 1.2 and 10 meters. (Note that for the tests over grass, a small strip of asphalt existed along the "grass" path between the 450 and 675 m positions.)

Along with the excess attenuation measurements, the mean weather conditions were evaluated extensively with meteorological instrumentation on 7 and 10 meter towers and a captive weather balloon repeatedly raised to and lowered from a height of 100 m. For the sake of brevity, only a small fraction of the available excess attenuation data are shown here in Figure 13. The figure shows, for two distances, the two surfaces and three source heights, the arithmetically averaged excess attenuation for one third octave bands of noise from 50 to at least 3200 Hz for the four to six replications of nominally very similar inversion conditions. Each excess attenuation measurement was based on an energy average of sound levels over a 15 second period. The standard deviation of the excess attenuation values over the four to six replications for each measurement condition and frequency was normally much less than 1.5 dB.

The results show the characteristic increase in excess attenuation due to ground absorption at frequencies in the range of 125 to 630 Hz depending on the surface and measurement distance. The excess attenuation data are augmented by some very limited measurements of surface impedance employing the simple technique developed by Piercy and Embleton.[7] Thus, these data provide another, and, in some aspects more complete, set of measurements of ground attenuation in the presence of documented refraction conditions than had been available previously. They offer a useful set of measurements for comparison with corresponding theoretical models.

CONCLUSIONS

Results from three different NASA conducted or NASA sponsored tests of long range sound propagation have been very briefly reviewed. The objective has been to identify these unique sources of data, two of which are over 25 years old, for the benefit of modelers of long range sound propagation who may not be aware of their existence. They offer potentially useful data sets for comparison with theoretical models for the evaluation, respectively of: scattering attenuation by atmospheric turbulence, long range ground propagation under a wide range of defined refraction conditions, and ground attenuation over two surfaces for nearly identical mild inversion conditions. As further advances are made in theoretical models, new and more sophisticated measurements will be required to validate the theory.

REFERENCES

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2. Polly, R. "Acoustic levels resulting from F-I Test TFW-016 and Saturn Test SA-19," Memorandum R-Test-ICA-73-64, Acoustics Section, Components Instrumentation Branch, Test Laboratory NASA GCMSFC, Huntsville, Alabama, April 16, 1964.

3. Sutherland, L. C. "Scattering attenuation of sound in the lower atmosphere," J. Acoust. Soc. Amer. 49:129(A), 1971.

4. Brown, E.H. and Clifford, S.F. "On the attenuation of sound by turbulence," J. Acoust. Soc. Amer. 60:788-794, 1976.

5. Tedrick, R.N. and Polly, R. "Measured acoustic propagation parameters in the Mississippi Test Operations area," NASA TM X-1132, August 1965.

6. Sutherland, L.C. and Brown, R. "Static tests of excess ground attenuation at Wallops Flight Center," NASA CR-3435, June 1981.

7. Piercy, J.E. and Embleton, T.F.W. "Excess attenuation or impedance of common ground surfaces characterized by flow resistance," J. Acoust. Soc. Amer. 65(S1), S63(A), 1979.

BACK-TO-BACK TESTS OF S-I & F-I ROCKETS AT NASA, MSFC - HUNTSVILLE

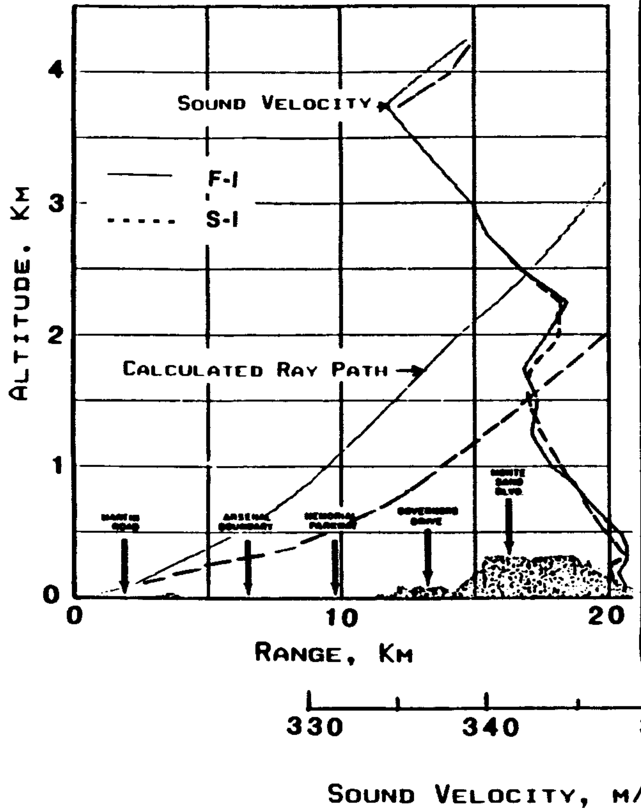

Figure 1A. Sound Velocity Profile

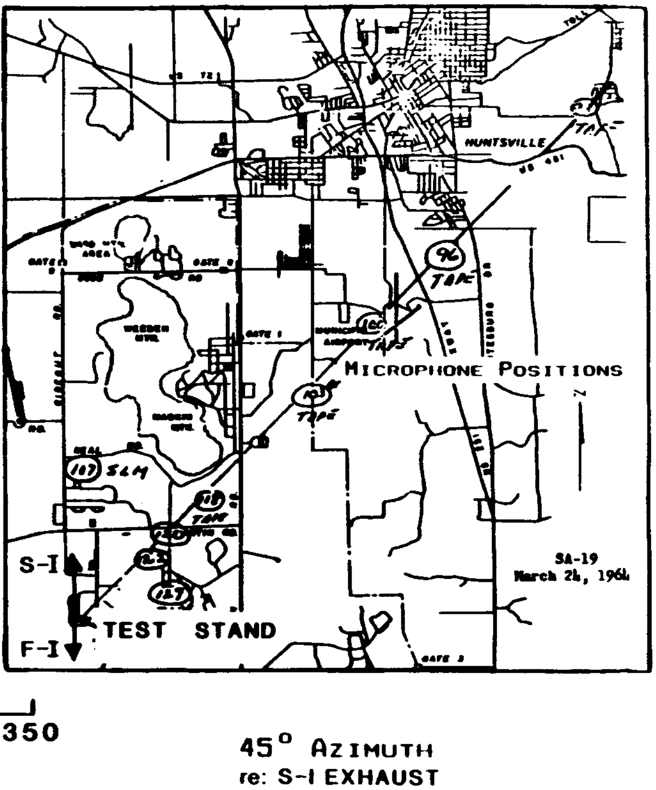

Figure 1B. Microphone Positions

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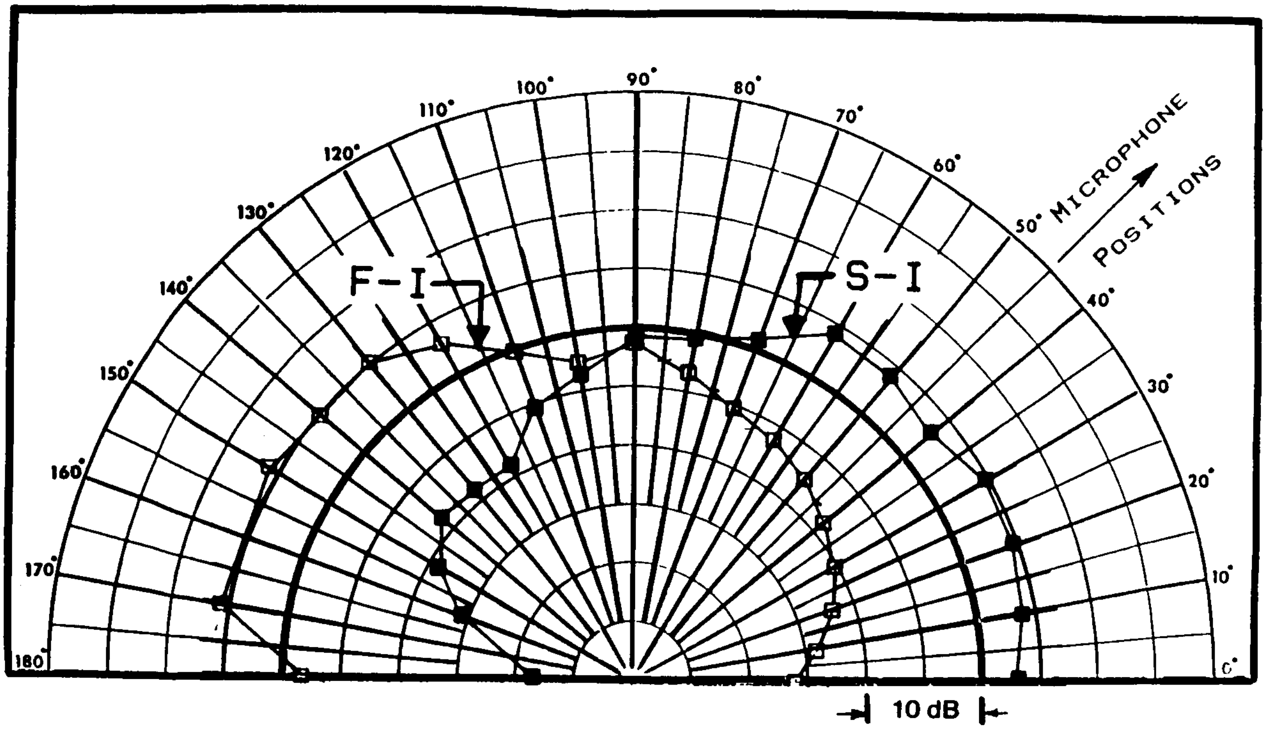

Figure 2. Directivity of S-I and F-I Rockets

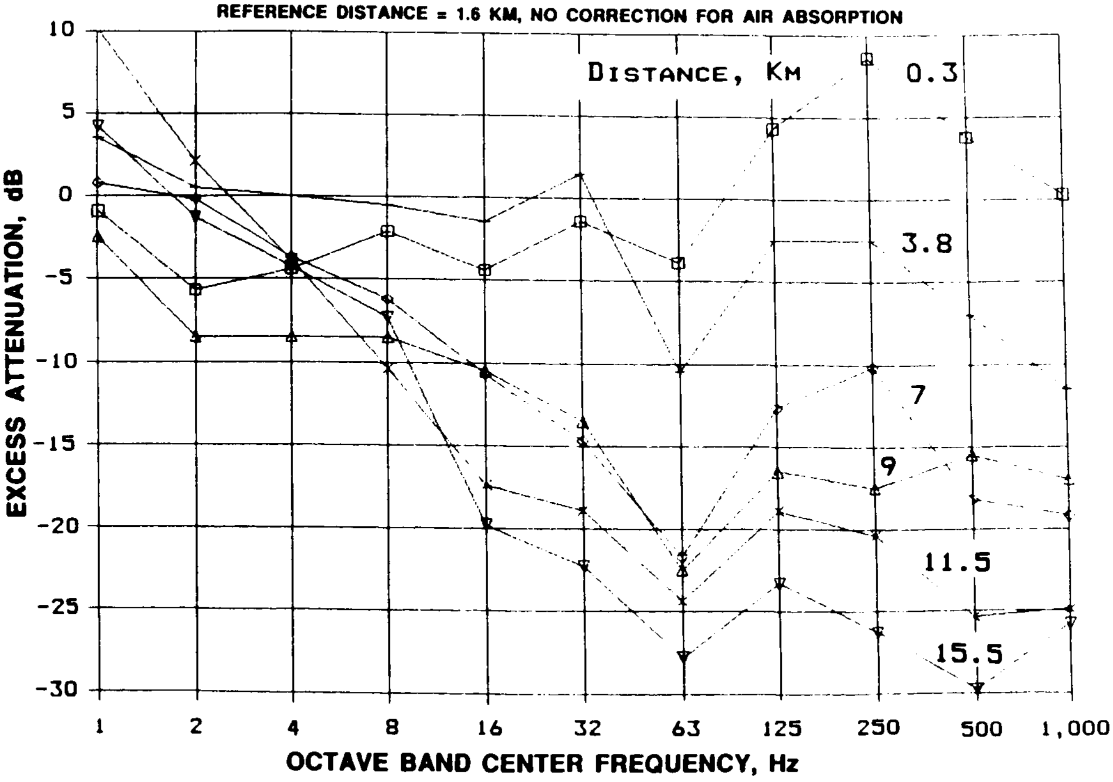

Figure 3. Excess Attenuation (S-I) Versus Frequency

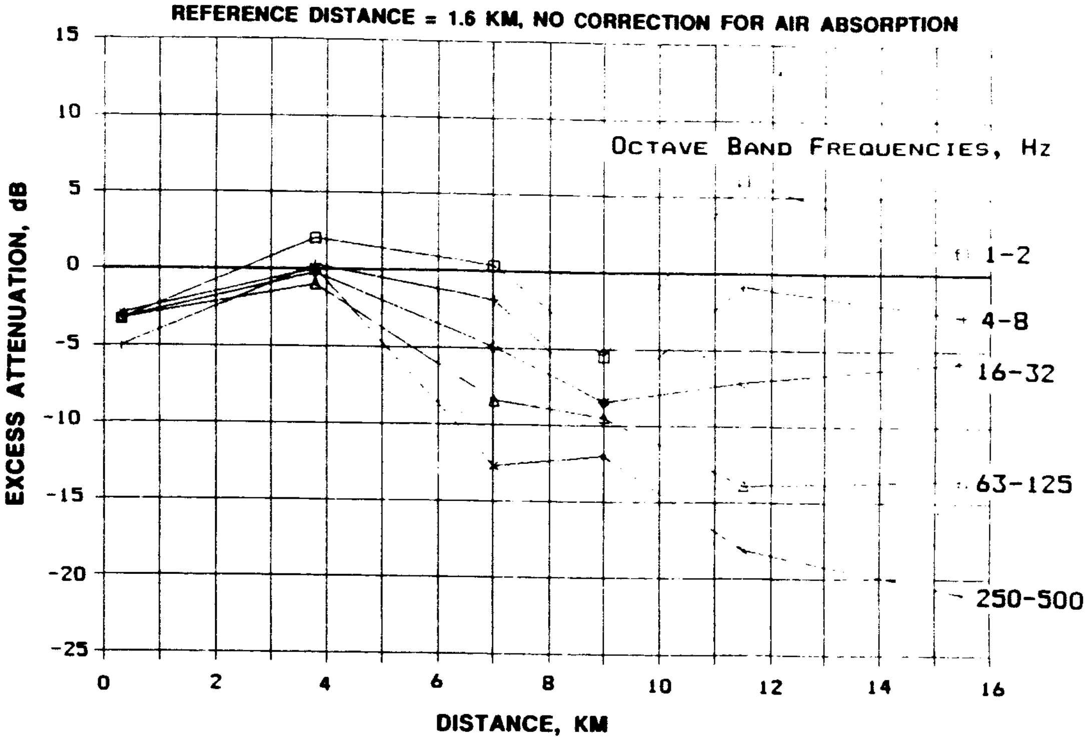

Figure 4. Excess Attenuation Versus Distance (S-I)

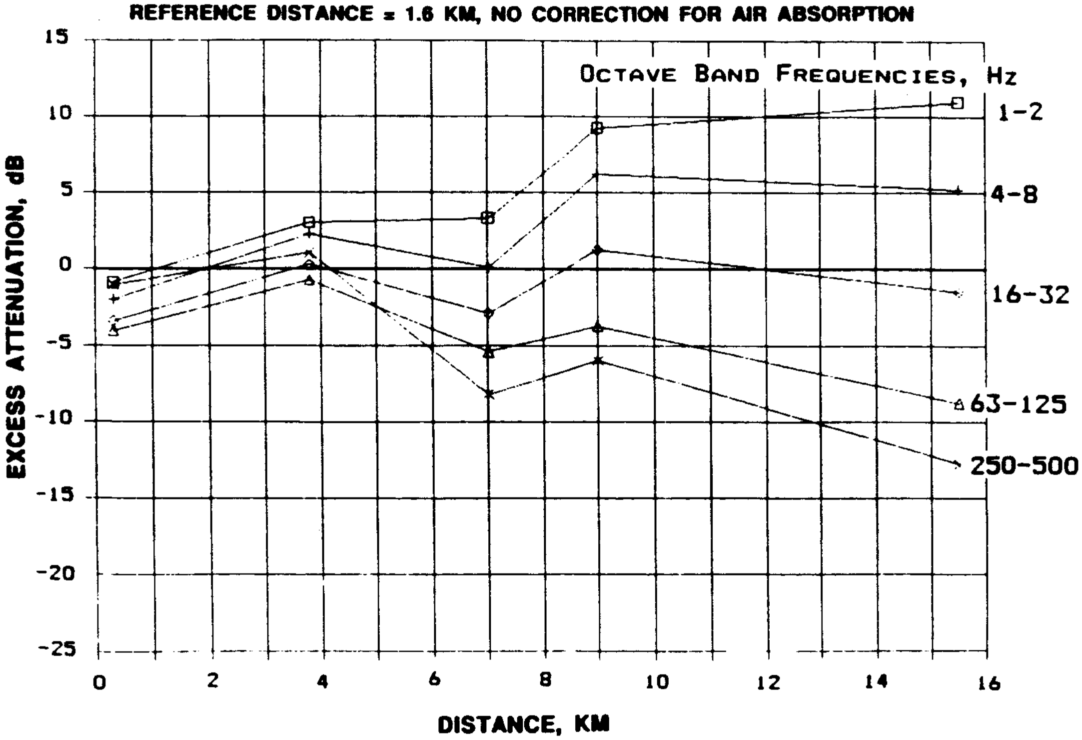

Figure 5. Excess Attenuation Versus Distance (F-I)

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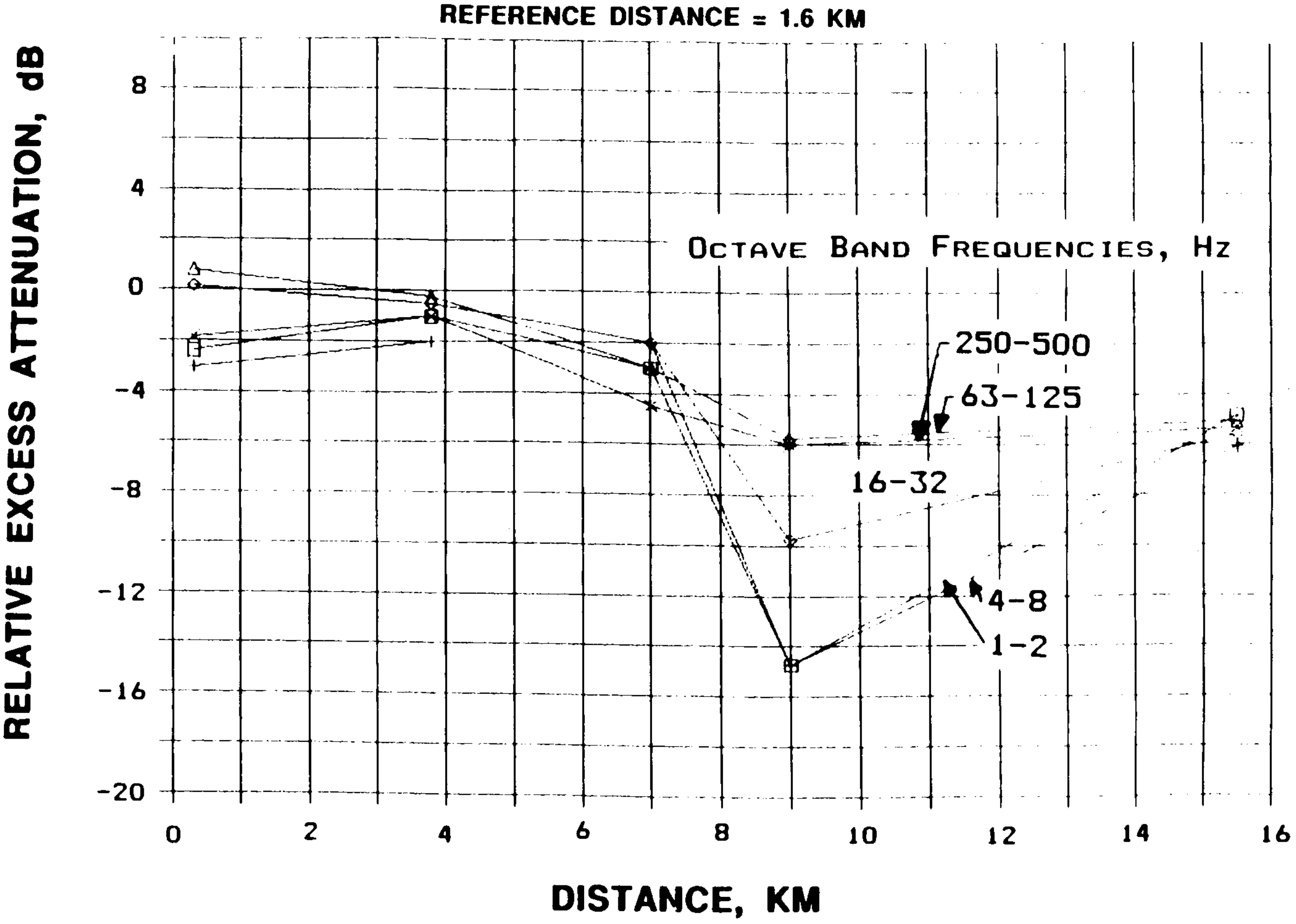
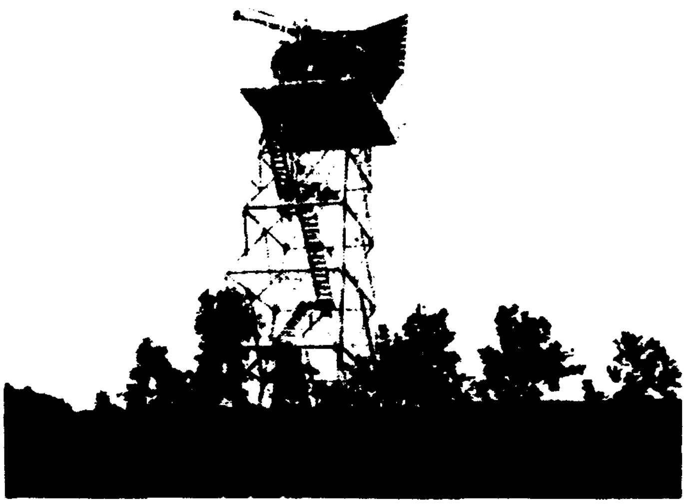


Figure 6. Relative Excess Attenuation (S-I) (F-I)



12.5 FT. DIAM. HORN ON 60 FT TOWER

Figure 7. Study of Sound Refraction at the Mississippi Test Range (from Tedrick and Polly, NASA TM X-132, 1965).

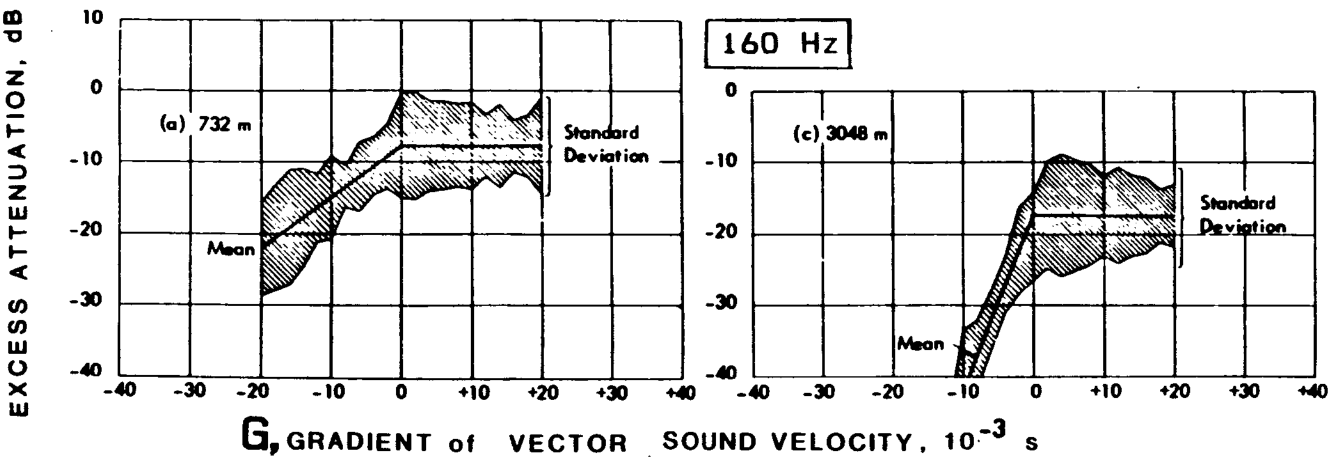


Figure 8. Attenuation in Excess of Inverse Square Loss

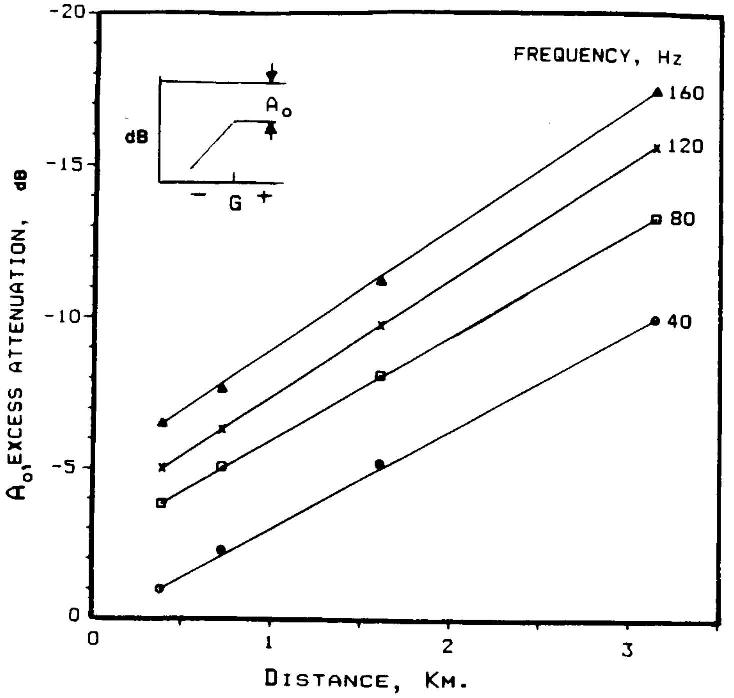


Figure 9. Excess Attenuation for Positive Sound Velocity Gradient

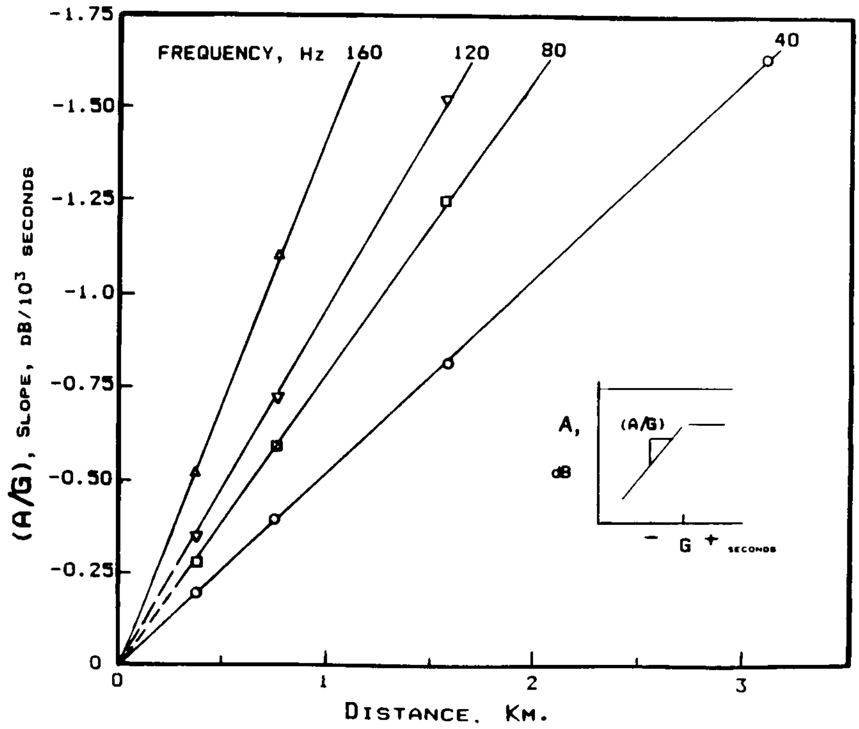


Figure 10. Slope of Excess Attenuation for Negative Sound Velocity Gradient

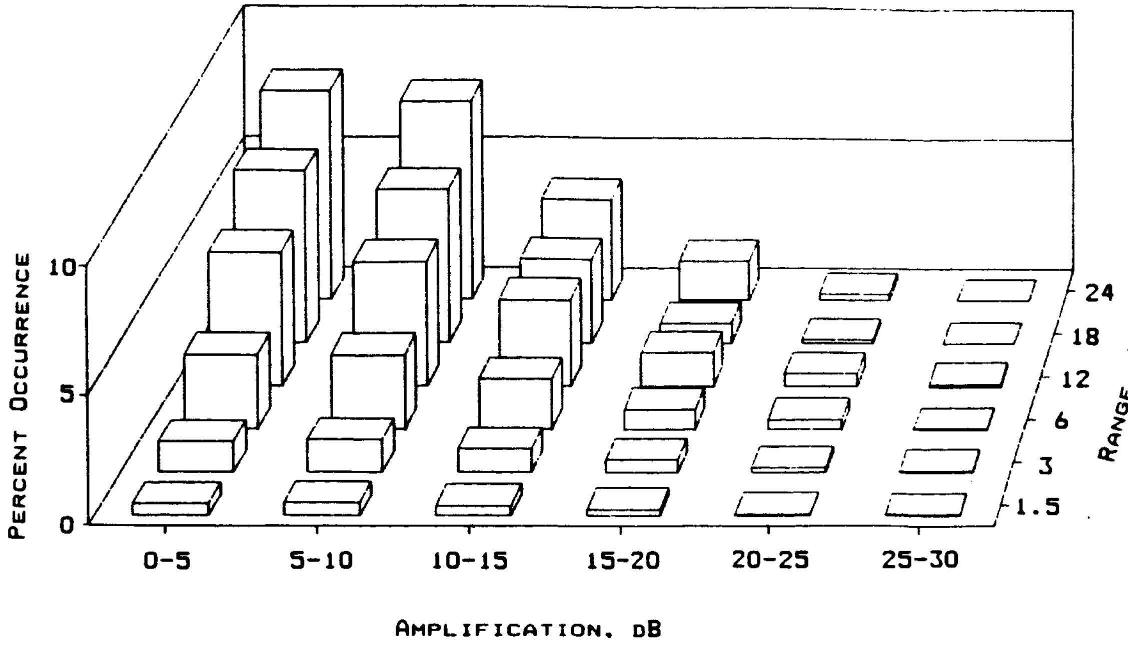
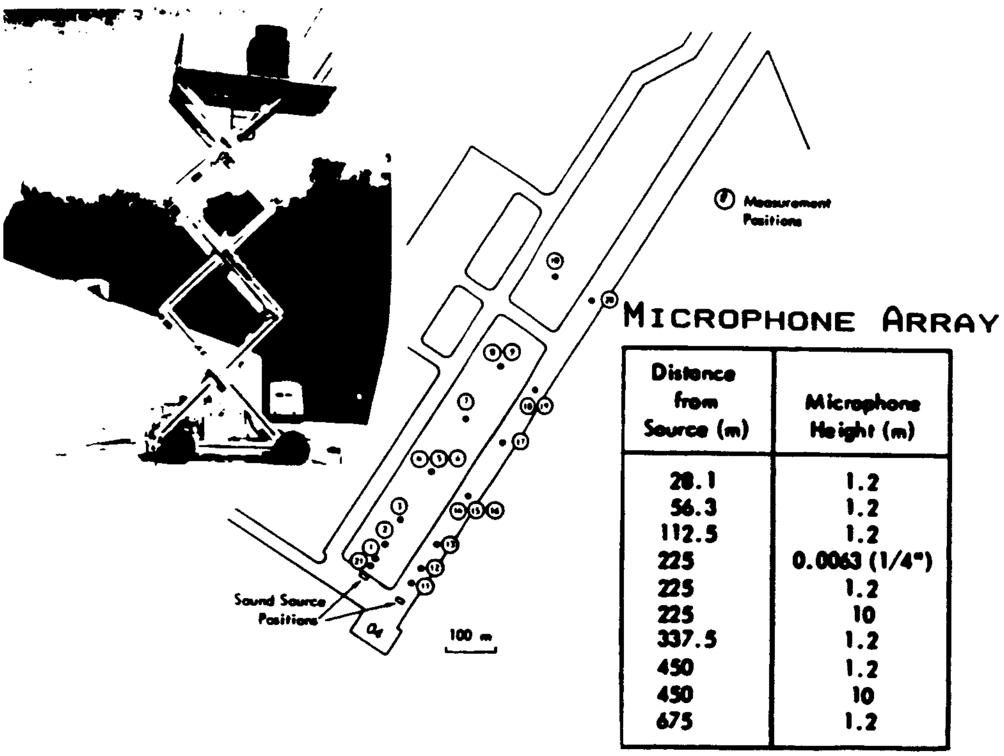


Figure 11. Distribution of Focusing Amplification by Range and Magnitude of Amplification



Distance from Source (m)	Microphone Height (m)
28.1	1.2
56.3	1.2
112.5	1.2
225	0.0063 (1/4")
225	1.2
225	10
337.5	1.2
450	1.2
450	10
675	1.2

Figure 12. Ground Attenuation Measurements at Wallops Island (Taken from Sutherland and Brown, NASA CR-3435, 1981)

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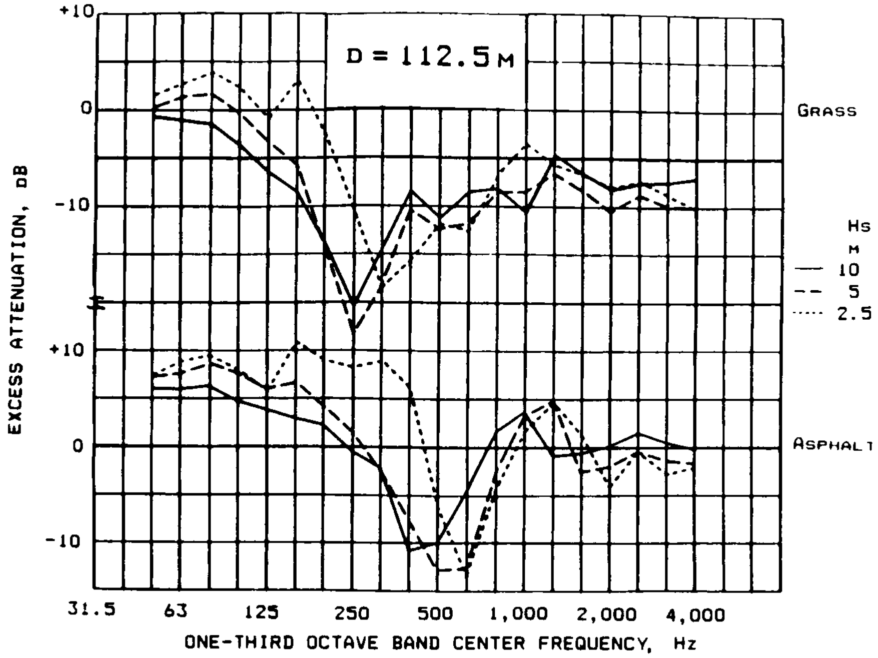

Figure 13A. Excess Ground Attenuation Corrected for Air Absorption (D = 112.5m)

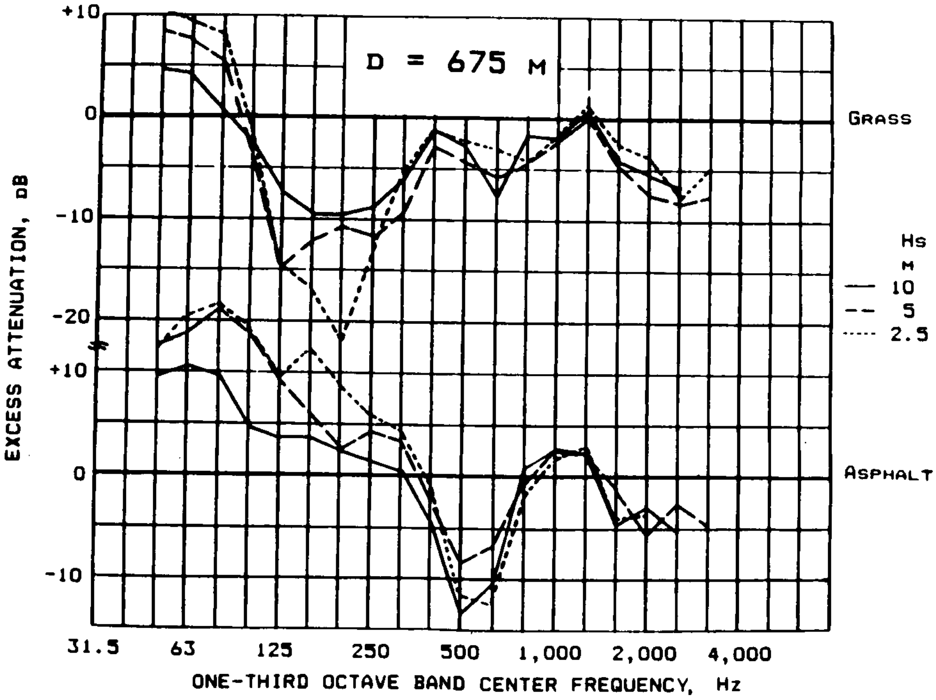

Figure 13B. Excess Ground Attenuation Corrected for Air Absorption (D = 675m)