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Bottom Backscattering Measured Southwest of Key West During Littoral Warfare Advanced Development Focused Technology Experiment 97-2

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13. ABSTRACT (*Maximum 200 words*)

Measurements of ocean bottom backscattering were performed in a shallow water environment southwest of Key West, Florida, as part of the Littoral Warfare Advanced Development (LWAD) Focused Technology Experiment 97-2 (FTE 97-2). Scattering strengths were obtained at 2, 2.5, 3 and 3.5 kHz as a function of grazing angle at a single site with a sandy bottom. The scattering strengths roughly followed a Lambert's Law (dependence on the square of the sine of the grazing angle) dependence with constants ranging from –22 dB for 2000 Hz to –19 dB for 3500 Hz. This frequency dependence was consistent with the results given by the Mourad-Jackson bottom scattering model.

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BOTTOM BACKSCATTERING MEASURED SOUTHWEST OF KEY WEST DURING LITTORAL WARFARE ADVANCED DEVELOPMENT FOCUSED TECHNOLOGY EXPERIMENT 97-2

1 Introduction

The Littoral Warfare Advanced Development Focused Technology Experiment 97-2 (LWAD FTE 97-2) was conducted in a shallow water area approximately 16 nmi southwest of Key West in March 1997. Bottom backscattering data at 2, 2.5, 3 and 3.5 kHz were obtained at a single site on the eastern edge of the test area. A map of the area is shown in Figure 1.

As a source of strong and persistent low-Doppler reverberation and clutter, acoustic interaction with the ocean bottom must be understood and quantified, especially in littoral-water environments where it can be the limiting factor in active sonar performance. Bottom scattering strength (BSS) is a standard input to active system performance prediction models, providing a characterization of bottom interaction for sound paths that backscatter from the ocean bottom and return to the receiver. A description of the issues involved in measuring BSS and its calculation from the sonar equation is given in Reference 1, where results from an earlier LWAD test (FTE 96-2) off the South Carolina coast are shown.

The FTE 97-2 bottom backscattering analysis in this report includes a brief description of the bottom characteristics of the test area. Then the measured BSS is shown as a function of frequency and grazing angle. A comparison is made between the observed scattering levels, a survey of historical data compiled by McCammon [2], and the scattering strength model of Mourad and Jackson [3].

2 Experiment geometry and data analysis

The bottom scattering tests were conducted from the research vessel ACOUSTIC PIONEER. Figure 2 gives a schematic diagram of the experimental geometry. A vertical line array (VLA) and a source were deployed on a single cable, with the source located 2.7 m above the center of the VLA. This resulted in a nearly monostatic measurement geometry.

The source was an directional ring transducer (USRD G81) that gave maximum (over launch angle) root-mean-square source levels of 194-195 dB at all transmisison frequencies. The source beam pattern features a null in the upward direction and some flattening in the downward direction. This beam pattern gave maximum source level for all of the launch directions used to calculate scattering strength, so the deviations from the omnidirectional pattern did not affect the BSS calculation. However, the source directionality does help to mitigate sidelobe interference for very high grazing-angle returns such as the initial acoustic interactions with the ocean surface and bottom. The source was deployed at a depth of 71.5 m, and transmitted 50-millisecond CW's at frequencies of 2.0, 2.5, 3.0, and 3.5 kHz. Sets of 10 identical pings were transmitted at each frequency, with individual pings separated by 15 s.

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Bottom reverberation from the 50-millisecond pulses was received on a 9-hydrophone aperture of the VLA. The hydrophones were spaced at 21 cm, which corresponded to a half-wavelength spacing of 3570 Hz. Ten beams with cosine-spaced main response axes were formed from the aperture, with the returns of interest coming from the three downward-looking beams closest to broadside. For LWAD FTE 97-2, the maximum horizontal range for a scatterer-to-receiver path used for bottom scattering strength calculation was approximately 1.6 km.

After beamforming, power spectra were obtained using 50-millisecond FFT's with 50 percent overlap. A frequency band representing the total energy about the zero-Doppler peak was selected and a time series was created for each ping including only the energy in this band. The direct arrivals for the pings were then temporally aligned and the various pings were averaged to produced a single reverberation curve for each beam and frequency bin. Integration over the roughly zero-Doppler spectral peak produced the total returned power as a function of time and beam. By calculating geometric spreading loss along each ray path, the transmission loss terms to and from the scattering patch were obtained. Finally, the computed beam pattern and raytrace were used to calculate the scattering patch area. From these inputs, BSS was calculated from the sonar equation as a function of beam, frequency and grazing angle, as shown in Reference 1. Additional details about the processing scheme are given by Ogden and Erskine [4].

3 Bottom description

A water depth of 224 m was obtained from the ship fathometer for the scattering site. (The DBDB5 database does not produce this result, as seen in Figure 1. This is presumably due to undersampling.) The LWAD FTE 97-2 area occupies what is known as the Pourtales Terrace. Geology and bathymentry for the area are described in References 5 and 6 and are briefly summarized here.

The Terrace is the southern end of the Floridian Plateau and has a boundary with the Straits of Florida. On its western edge lies the LWAD FTE 97-2 site. Figure 3, taken from Reference 7, provides a map of the main bottom features. The terrace begins on the north at the 100 fathom isobath (187 m) and extends southward to a depth of 160 fathoms (293 m) where it terminates at the Pourtales escarpment. The Terrace is a down-dropped segment of continental shelf material of Miocene-age limestone as determined by sampling and seismic refraction studies. This submerged ledge of limestone has a variable thickness veneer of post-Miocene carbonate sediments. While sediment samples on the terrace are carbonates, primarily of organic origin, the sizes range from clay to silt to sand, with larger sizes present locally.

The sediment grab obtained during the LWAD FTE 97-2 experiment revealed a carbonate sand composition at the bottom scattering test site [8]. The top thirty meters would be expected to have an increase in compressional speed from 1600 m/s to 1650 m/s, an attenuation of 0.27 dB/m*kHz (at 3000 Hz this would be .81 dB/m), and a density of 1.6 g/cc. It is difficult to say how deep the sediment layer actually is at any particular location. It is unlikely that there is acoustic interaction with the underlying limestone at the sediment site, although this may not necessarily be true for the entire test area.

4 Scattering strength results

The bottom scattering strengths obtained at the four transmitted frequencies are shown in Figures 4-6 for receiver beams 2, 3 and 4 respectively. These beams correspond to main response axes of 33.8, 19.5 and 6.4 degrees downwards relative to horizontal. The beams intersect the bottom at slightly different grazing angles, but the scattering level is (to within experimental error) independent of beam. For this experimental geometry, the grazing angles for the source-to-scatterer and scatterer-to-receiver are similar (within tenths of a degree), so only one angle needs to be considered in the analysis. A reference curve showing Lambert's law with a coefficient of -27 dB is provided. This curve represents a standard input to active sonar performance models, with the selection of the -27 dB value originating in the work of MacKenzie [9]. Data points above the reference curve represent the potential for underestimating the reverberation background and obtaining errors in system performance prediction via the standard model. All of the FTE 97-2 data points represent stronger scattering than the assumption by the standard model.

For all three beams, there was a slight increase in scattering strength with frequency. The results on beam 3 for the four frequencies are shown in Figure 7. This kind of frequency dependence was obtained when the bottom backscattering model of Mourad and Jackson (Reference 3) was used. The geoacoustic parameters given in the previous section were entered into the model and the bottom roughness properties were guessed. Data and model both suggest a minimal increase in BSS with increasing frequency, as seen in Figure 8. (The data/model match in absolute level is not of great interest, as the bottom roughness parameters were freely varied to produce this data/model agreement.)

The extrapolation of these results to the entire test area does present a potential problem. Sediment cover may become thin, and limestone may become exposed. The scattering off of exposed limestone could be 15-20 dB higher, as was shown in Reference 1, where data was obtained for sand and limestone bottoms. Bowles and Lambert mapped sediment thicknesses in an area to the west and found an area of unsedimented bottom that extended at least as far east as 82 deg 5 min W. Therefore, it is quite probable that areas of unsedimented bottom can be found in the western part of the test area.

5 Model fits to scattering results

The scattering data can be represented by a Lambert's law model [10] for the measured grazing angle region (15-35 degrees):

$$BSS = 10\log(\sin^2\theta) + \mu \tag{1}$$

Beam-averaged values of μ for the four frequencies are given in Table 1 for this Lambert's law model. McCammon [2] gives -27.5 ± 6.8 dB as an average μ value for fine sand and silt bottoms assuming a $\sin\theta$ dependence instead of $\sin^2\theta$. If $\sin\theta$ dependence is assumed, which generally gives slightly inferior curve fits for the FTE 97-2 data, the μ values would become -25.7 dB (2000 Hz), -25.4 dB (2500 Hz), -24.7 dB (3000 Hz) and -23.0 dB (3500 Hz). These modified values all fall within McCammon's interval.

Table 1: Values of μ for LWAD FTE 97-2 (assuming $\sin^2\theta$ model)

Frequency (Hz)	μ (dB)
2000	-22.1
2500	-21.4
3000	-20.7
3500	-18.7

6 Summary

During LWAD FTE 97-2 bottom backscattering strengths were measured at a single site within the test area (224 m water depth). A grab sample showed the bottom to be composed of sand. The measured data indicated grazing-angle dependence consistent with Lambert's Law, with a reasonable value for the constant μ for sandy bottoms. Frequency dependence on the order of a few dB was observed, and was consistent with the frequency dependence provided by a bottom scattering model. The scattering could be substantially higher for areas where the underlying limestone has been exposed.

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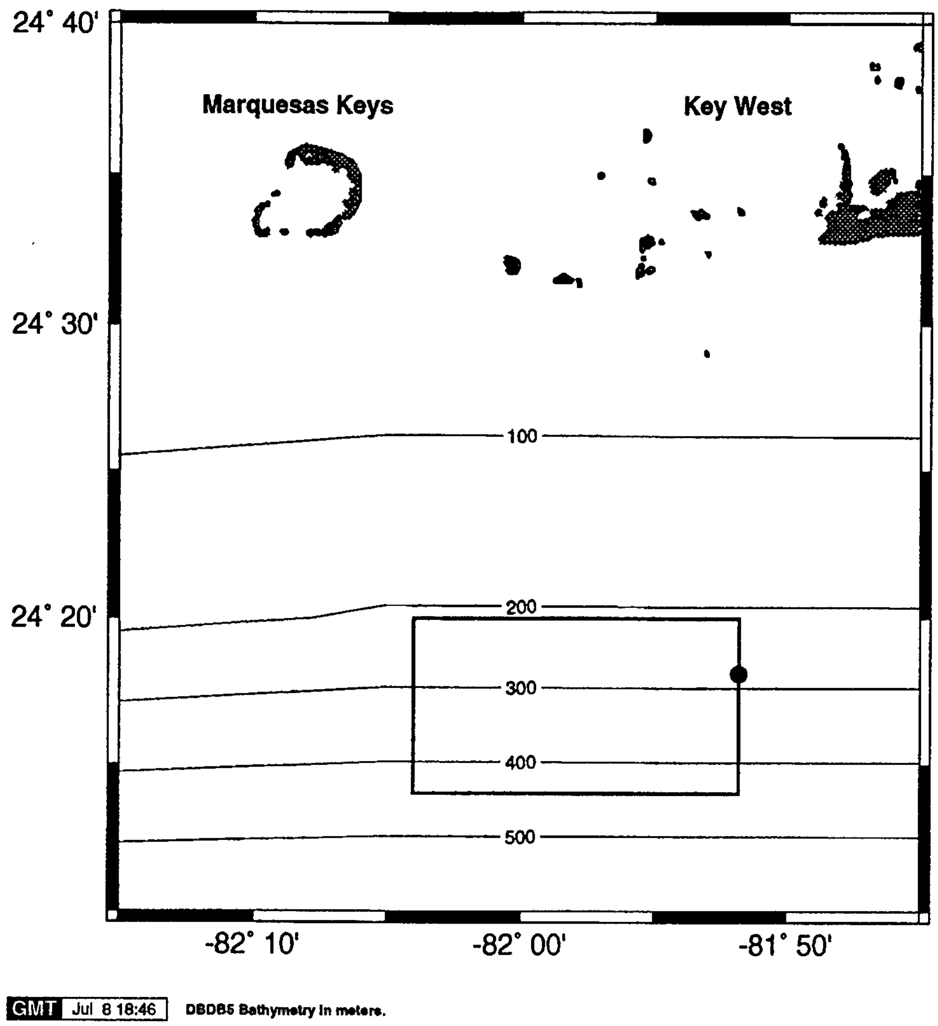

Figure 1: Map of the LWAD FTE 97-2 experiment area (rectangle). The black dot shows the bottom scattering strength site.

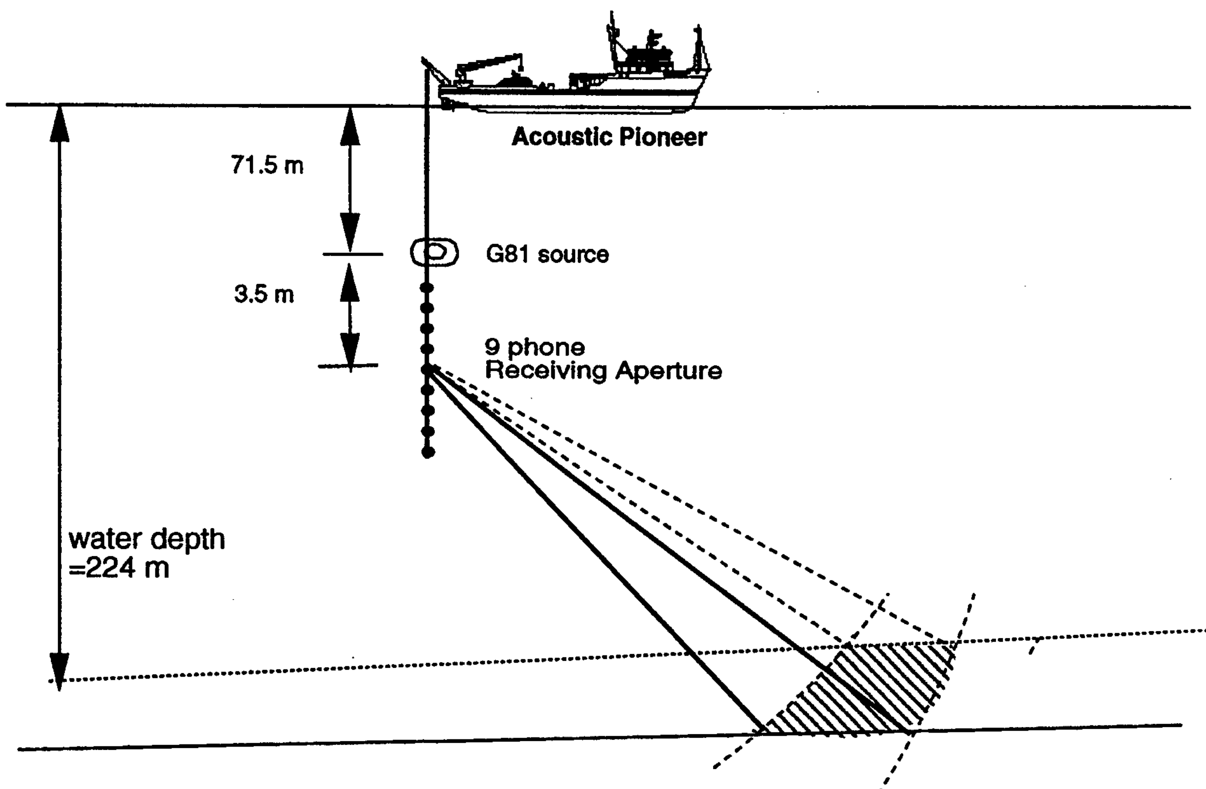

Figure 2: Depiction of the experimental geometry for bottom backscattering measurements in LWAD FTE 97-2. A sector of one receiver beam is shown and a sector of the scattering annulus is shaded.

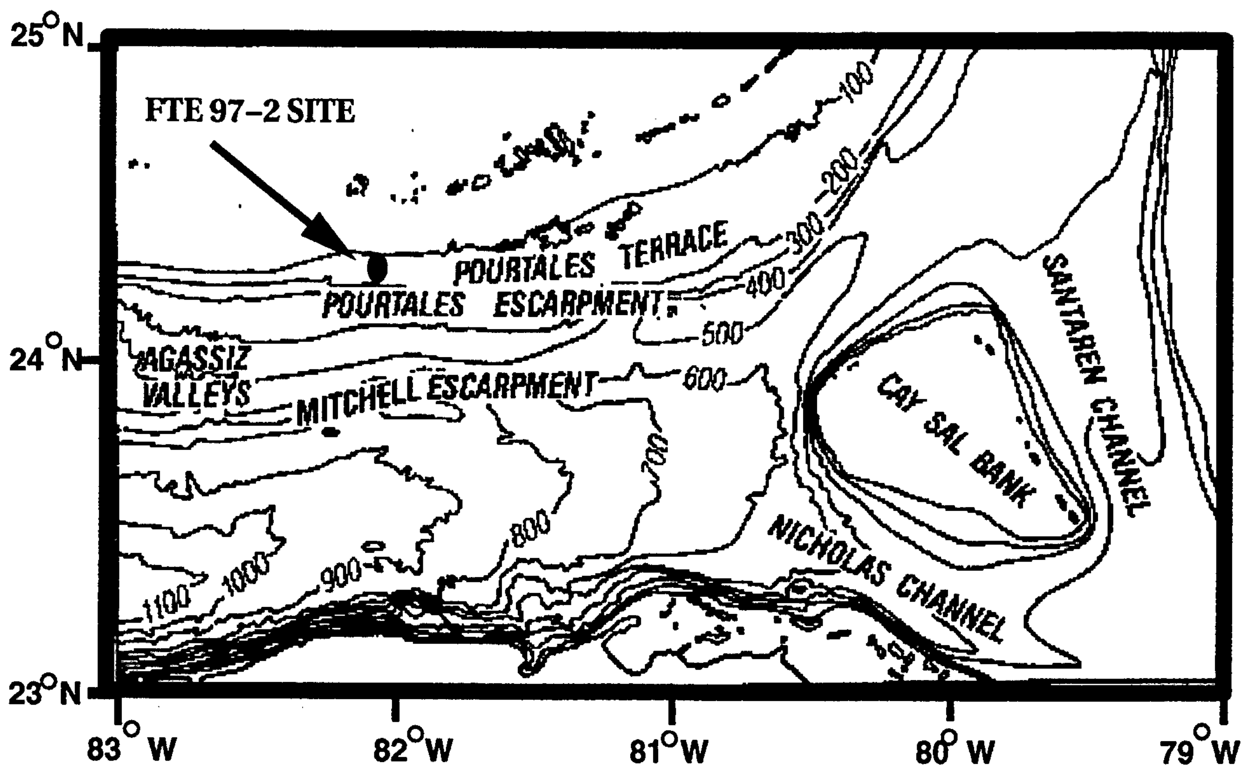

Figure 3: Map from Malloy and Hurley (1970) showing the main bathymetric features in the region. The contour depths are in meters.

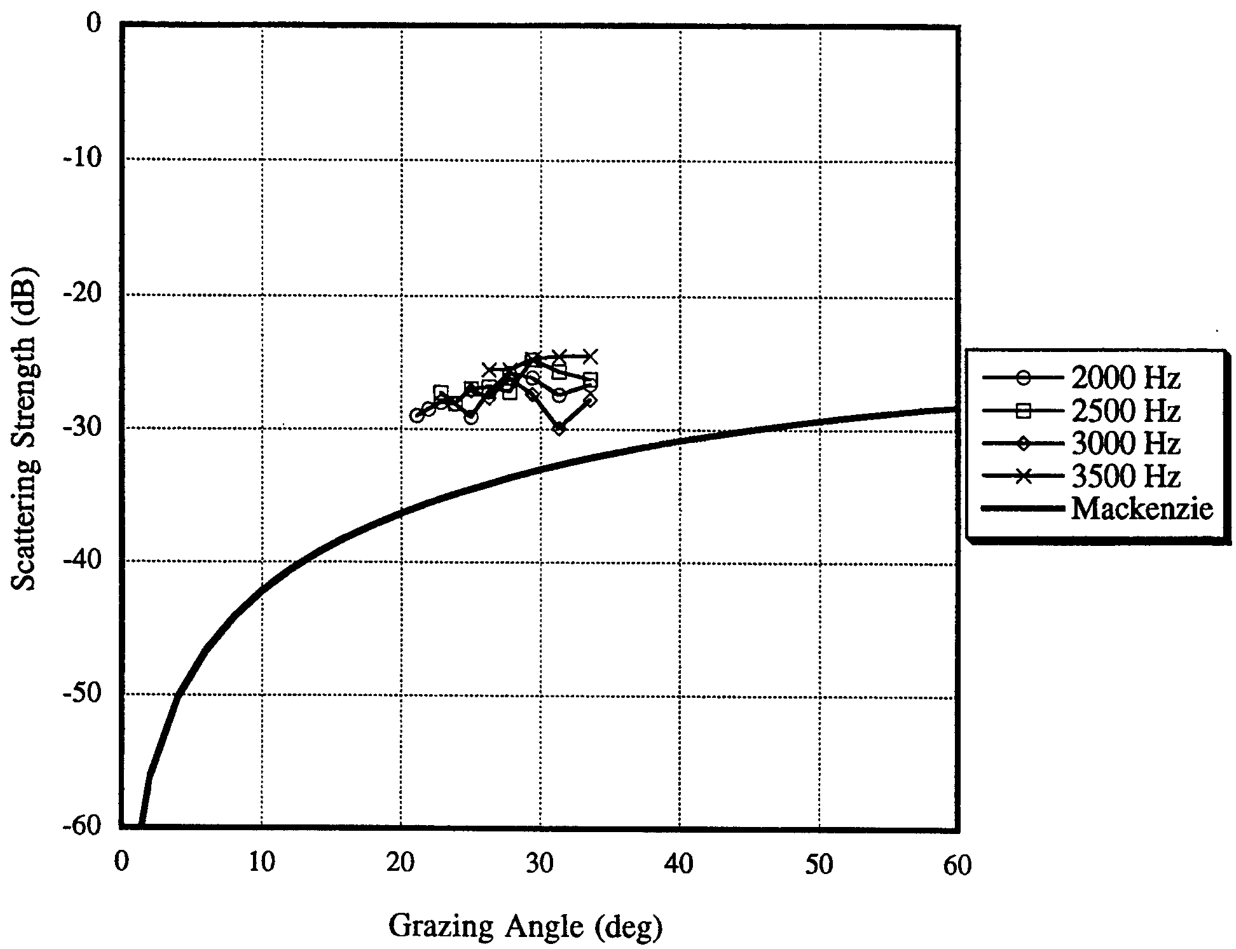

Figure 4: Bottom backscattering strengths at 2000 to 3500 Hz as a function of grazing angle for Beam 2. The reference curve for a standard (Mackenzie) model is also shown.

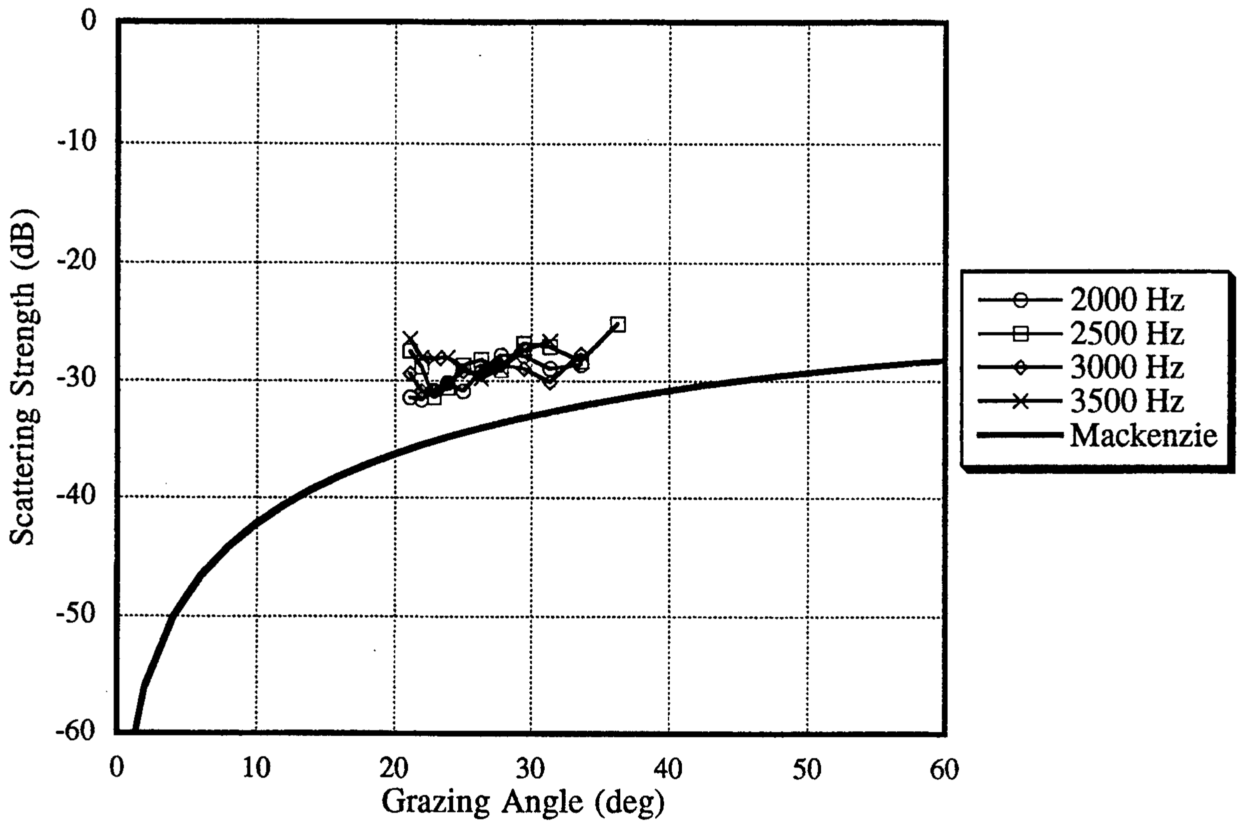

Figure 5: Bottom backscattering strengths at 2000 to 3500 Hz as a function of grazing angle for Beam 3.

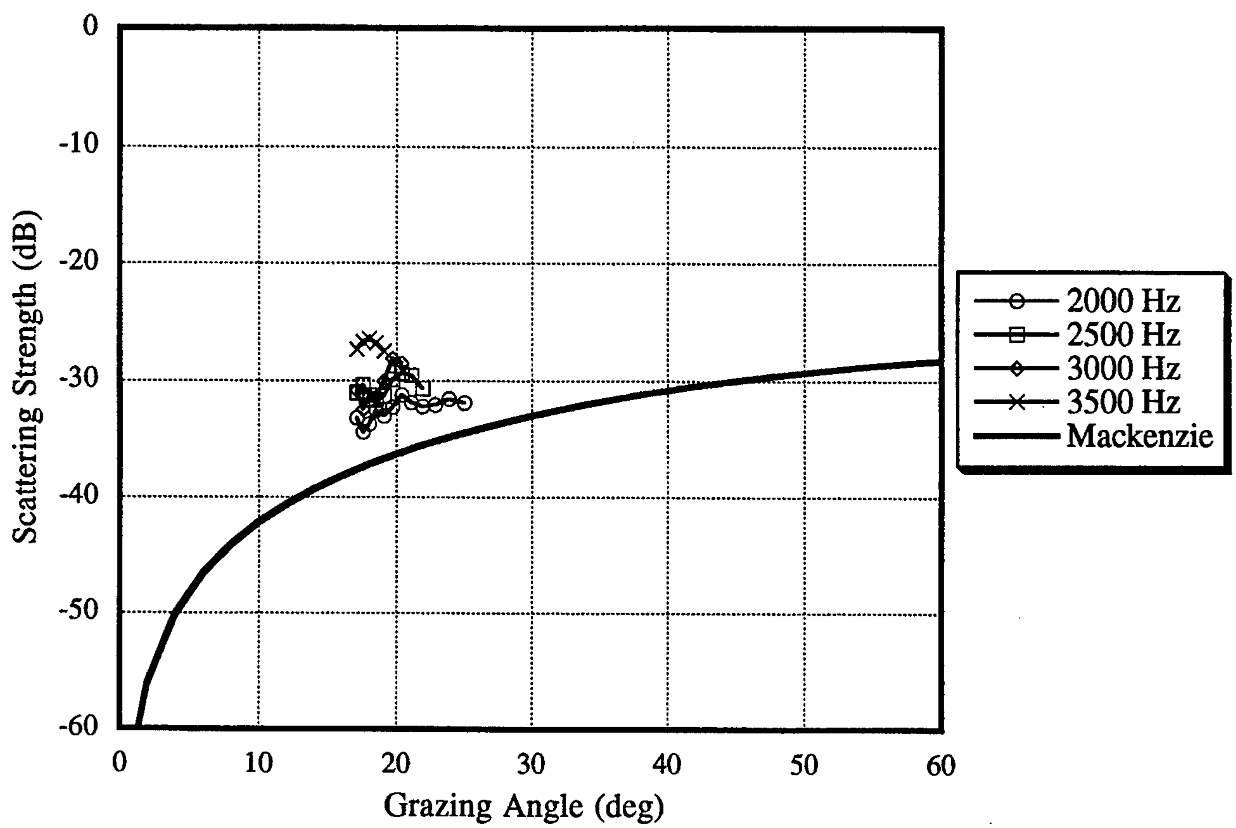

Figure 6: Bottom backscattering strengths at 2000 to 3500 Hz as a function of grazing angle for Beam 4.

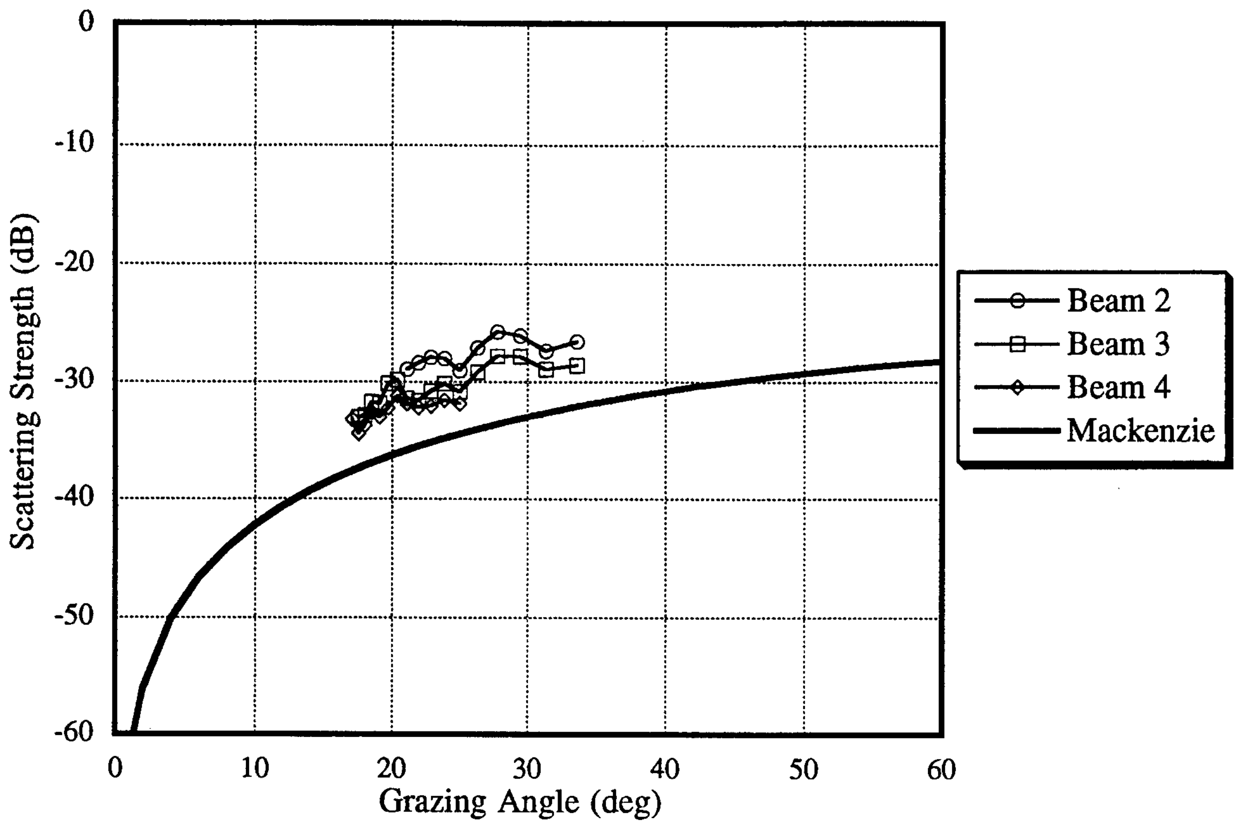

Figure 7: Bottom backscattering strengths at 2000 Hz as a function of grazing angle for Beams 2, 3, and 4.

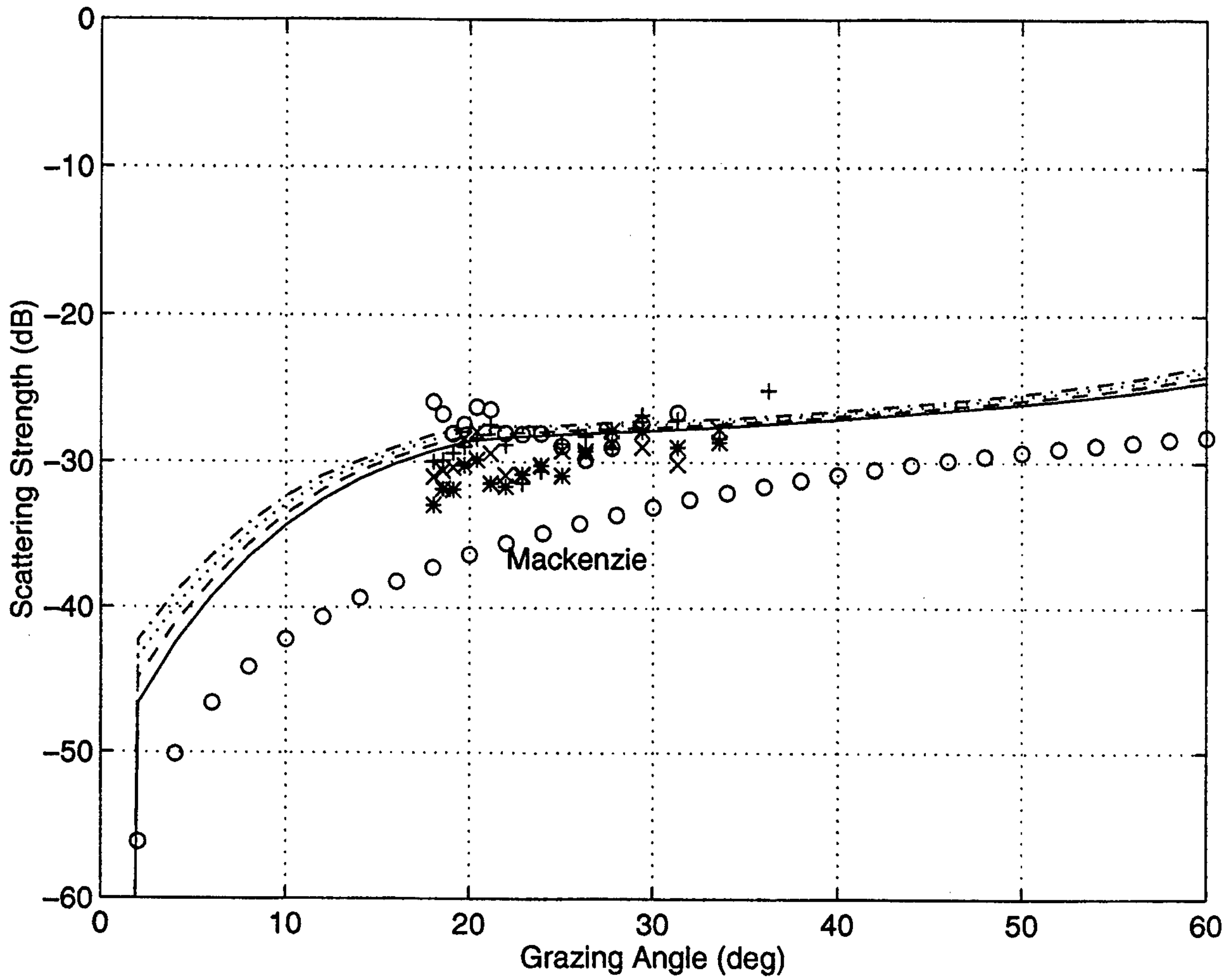

Figure 8: Bottom backscattering strengths at the four frequencies as a function of grazing angle for Beam 3, compared with the model of Mourad and Jackson. The data are indicated by '*' (2000 Hz), '+' (2500 Hz), 'x' (3000 Hz), and 'o' (3500 Hz). The model predictions are indicated by solid (2000 Hz), dashed (2500 Hz), dotted (3000 Hz) and dash-dot (3500 Hz) lines. The Mackenzie reference curve is also shown.