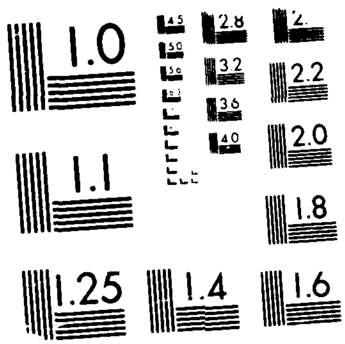

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An ice keel program that was described at the Spring 1985 meeting is used to investigate the acoustic scattering properties of ice keels at high frequency. Keels are modeled as parabolas. Sample sets of keels are generated using published distributions of spacing and sizes. A large number of rays are directed towards the keel set and the emerging rays are collected into angular bins. Reflections from and refraction through the ice are employed. Specular reflection coefficients computed in this manner are similar to published results above 3° grazing angle. No significant specular reflection is found at lower grazing angles. The scattered rays tend to be directed predominantly into angles near the specular angle. (Work supported by NOSC Independent Research.)

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Ray scattering from a collection of ice keels. David F. Gordon, (Naval Ocean Systems Center, Code 711 San Diego, CA 92152-5000)

An ice keel program that was described at the Spring 1985 meeting (paper 271) is used to investigate the acoustic scattering properties of ice keels at high frequency. Keels are modeled as parabolas. Sample sets of keels are generated using published distributiions of spacing and sizes [O. I. Diachok, J. Acocust. Soc. Am. 59, 1110-1120 (1976)]. A large number of rays are directed towards the keel set and the emerging rays are collected into angular bins. Reflections from and refraction through the ice are employed. Specular reflection coefficients computed in this manner are similar to published results (ibid Diachok) above 3° grazing angle. No significant specular reflection is found at lower grazing angles. The scattered rays tend to be directed predominantly into angles near the specular angle. [Work supported by NOSC Independant Research.]

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RAY SCATTERING FROM A COLLECTION OF ICE KEELS

by D. F. Gordon

To be delivered at 113th Meeting of the Acoustic Society of America,
Indianapolis, In, Session H, 12 May 1987

The scattering of rays by a random collection of ice keels has been investigated in a project funded by NAVOCEANSYSCEN Independent Research. The ray program used in this project was reported at the Austin meeting of the Acoustic Society in December 1985.

In a 1976 article in JASA O. I. Diachok showed that Twersky's boss scattering theory was an effective approach to under-ice acoustic scattering and propagation. A first term approximation from that theory was shown to give effective results for high frequencies, as did another at low frequencies. The current task derives high frequency numerical values similar to the above with the main difference being that the individual bosses are of random size.

In this paper I will first discuss the ice keel model used. Next, I will show the angular distribution of rays scattered from a set of keels and then the specular scattering coefficient. Finally, I will indicate some deficiencies in the model.

Viewgraph 1 shows a random set of ice keels with the interacting rays which will be discussed later. The individual keels are parabolas. The distance between keels is random, drawn from a rectangular distribution to give 9.5 keels per kilometer. The depth of the keels are drawn from a Rayleigh distribution with mean depth of 4m. A further parameter, the ratio of depth to width of 1 to 3.2. Therefore, the keels are all similar geometric figures. Most of these parameters are taken from Diachok's 1976 article.

Viewgraph 2 shows the details of an individual keel on an equal length-depth scale. This is the cross section of an elongated object. The maximum slope of the keel edge is at its upper edge and is 51°.

The keel model as shown was next modified to simulate an orientation of the keels which is random when viewed from above. This was done by increasing the width of the keels by a function of a random angle between 0 and 90°. This is approximately the secant of the angle. However, this function is modified by the fact that, in a given range interval, one is more likely to cross a keel near perpendicular to a path than one near parallel. The resulting modification to width is shown at the bottom of the figure, where x is a random number between 0 and 1.

Viewgraph 3 shows three sample keel sets that were used to estimate scattering. Sigma indicated on each one is the standard deviation of ice depth in meters. As you can see there is considerable variation in this parameter, although the three sets were generated by selecting random values from the same distributions. If the three sets are combined into one long set, it has a sigma of 2.1 m, or near average for observed Arctic ice roughness.

Ray scattering functions were derived as follows. A number of rays were launched at the same angle, but successive ranges to simulate a plane wave directed at the keel set at a given angle of incidence. Usually 800 rays were used. Rays leaving the keel set and crossing a given reciever depth are sorted into angular bins. Any reflection or transmission losses at boundaries alter the intensities of the accumulated rays. Spreading loss is accounted for by the collection into angular bins.

Two scattering processes are allowed in the computations. These are reflection at the ice-water interface and refraction through the keel. Refraction at both the shear and compressional speed in the ice is permitted. However, a few rays strike the keels at sufficiently large grazing angles for transmission at the compressional speed, so shear wave paths through the keels predominate.

Viewgraph 4 shows the angular distribution of scattered rays. The sum of rays in each 2° angular bin is expressed as a decibel by taking -10 log of the ratio of the ray sum in a bin to the total rays launched. Keel distribution A of viewgraph 3 was used. The surprising result here is that almost all rays are scattered into the foreward direction. Very small backscattering lobes can be seen for the steeper rays. Also, note that a significant specular component does not show up for angles of incidince below 6°.

The predominance of foreward scatter over back scatter results from the parabolic shape and from the water-ice reflection coefficients. One set of plane wave reflection and transmission coefficients is shown in Viewgraph 5. There are similar sets for the shear and compressional waves at the ice to water interface. These coefficients are functions of the shear and compressional wave speeds in the ice, the water sound speed and the density of the water and ice. Observed sea ice shear speeds vary over a wide range but here a value of 1600 m/s is used. This gives a critical grazing angle of 26°. Below this angle perfect reflection occurs for lossless media. Above this angle the reflection loss increases rapidly. Simultaneously the transmission loss into shear waves decreases rapidly. The ice becomes very transparent to the sound. This transparency at high grazing angles is a major cause of the preferential foreward scatter of the rays.

The absence of back scatter at low grazing angles is not so much a result of the reflection coefficients as of the shadowing of the upper steep slopes of the keels by adjacent keels.

Viewgraph 6 shows angular scattering diagrams for three angles for the three keel sets of viewgraph 3. Set A had a considerably higher roughness factor or sigma than B and C. However, no distinctly different characteristics are apparent in A.

The specular reflection coefficient is the most immediately useable product for propagation loss programs. This essentially measures the energy that remains coherent upon reflection from the rough surface. Viewgraph 7 shows this reflection coefficient as a function of grazing angle for the three keel sets. Below a grazing angle of 6° the larger roughness of set A seems to produce a larger scattering loss. At larger angles the roughness seems immaterial. The rays that contribute to this specular reflection are almost all those that reflect from the smooth surface without touching a keel. The function shown here is thus a measure of the unshadowed surface as seen from both the source and receiver.

Theory for constant depth bosses says the reflection loss, which becomes large at low grazing angles, should recover at very low angles and become zero at zero degree grazing angle. However, computations down to 0.75° with this program have shown no tendency towards recovery of the reflection loss.

Viewgraph 9 illustrates the most notable shortcomings of the model reported here. Perhaps the most noticeable is the absence of reflections from the far sides of the ice keels. These reflections might add significantly to the back scattering strengths of the keels. In a pure ray construction treatment, as used here, one must terminate internal reflections at some number or level. They were terminated here at zero.

A second important shortcoming is the absence of an ice plate which could alter ray paths. However, rays directed into the ice plate will readily pass back into the water because of the transmission coefficient.

Finally, attenuation of shear waves in the ice is omitted. This may very well add a decibel or more loss to paths through the ice; changing the angular scattering diagram. Its effect upon the reflection coefficient might reduce the specular reflection coefficient.

In conclusion, a model of ice keel scattering indicates that the high frequency scattering is predominantly in the foreward direction into angles below the horizontal of 0 to 50°. The specular reflection is a measure of the smooth surface, unshadowed by the keels.

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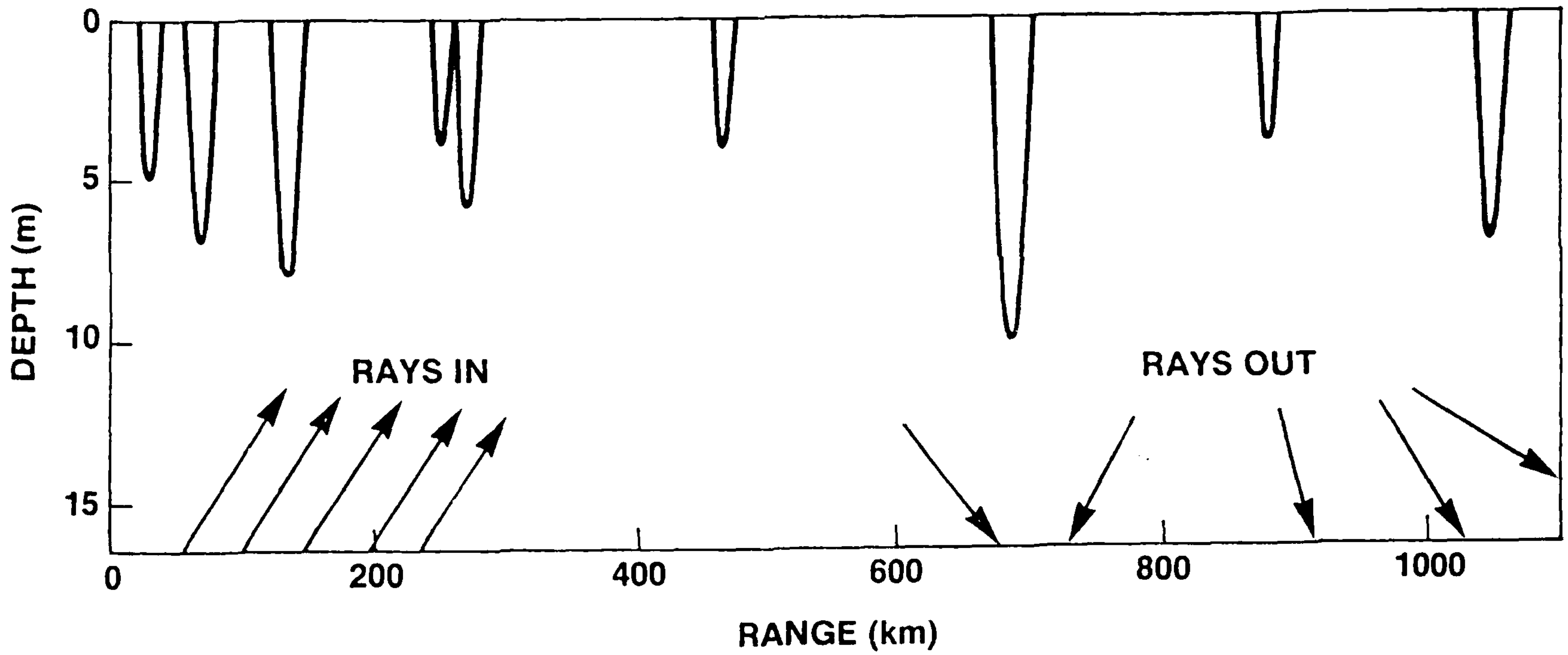
Ice Keel Sample with Scattered Rays



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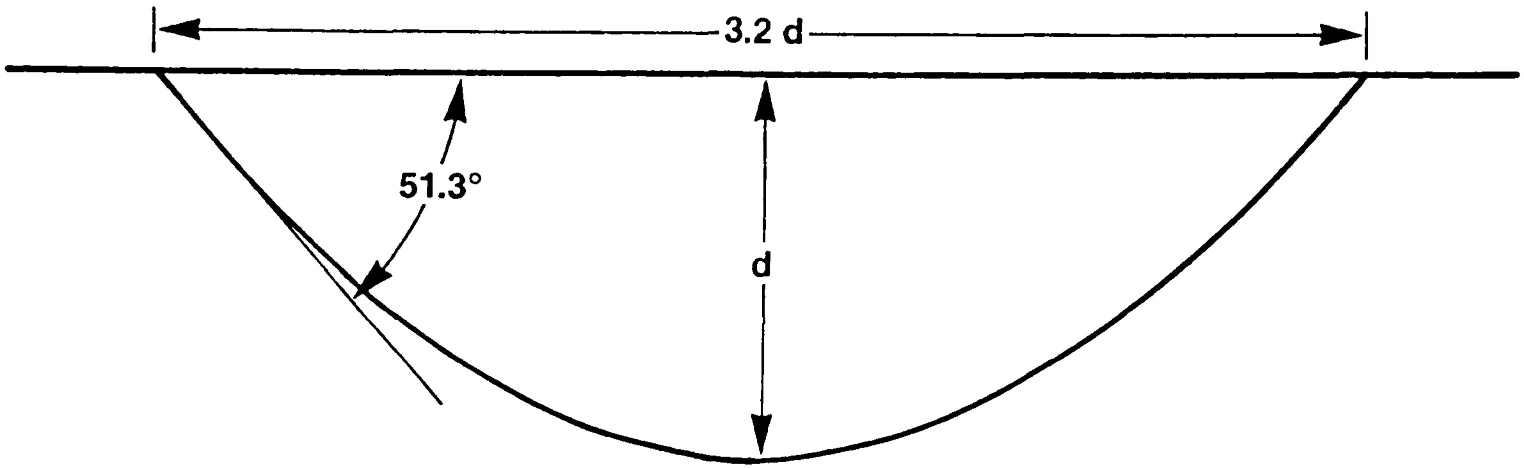
Cross Section of a Parabolic Ice Keel Model



For random orientation:

Multiply width by $(1 - x^2)^{-1/2}$

where x is random, $0 < x < 1$

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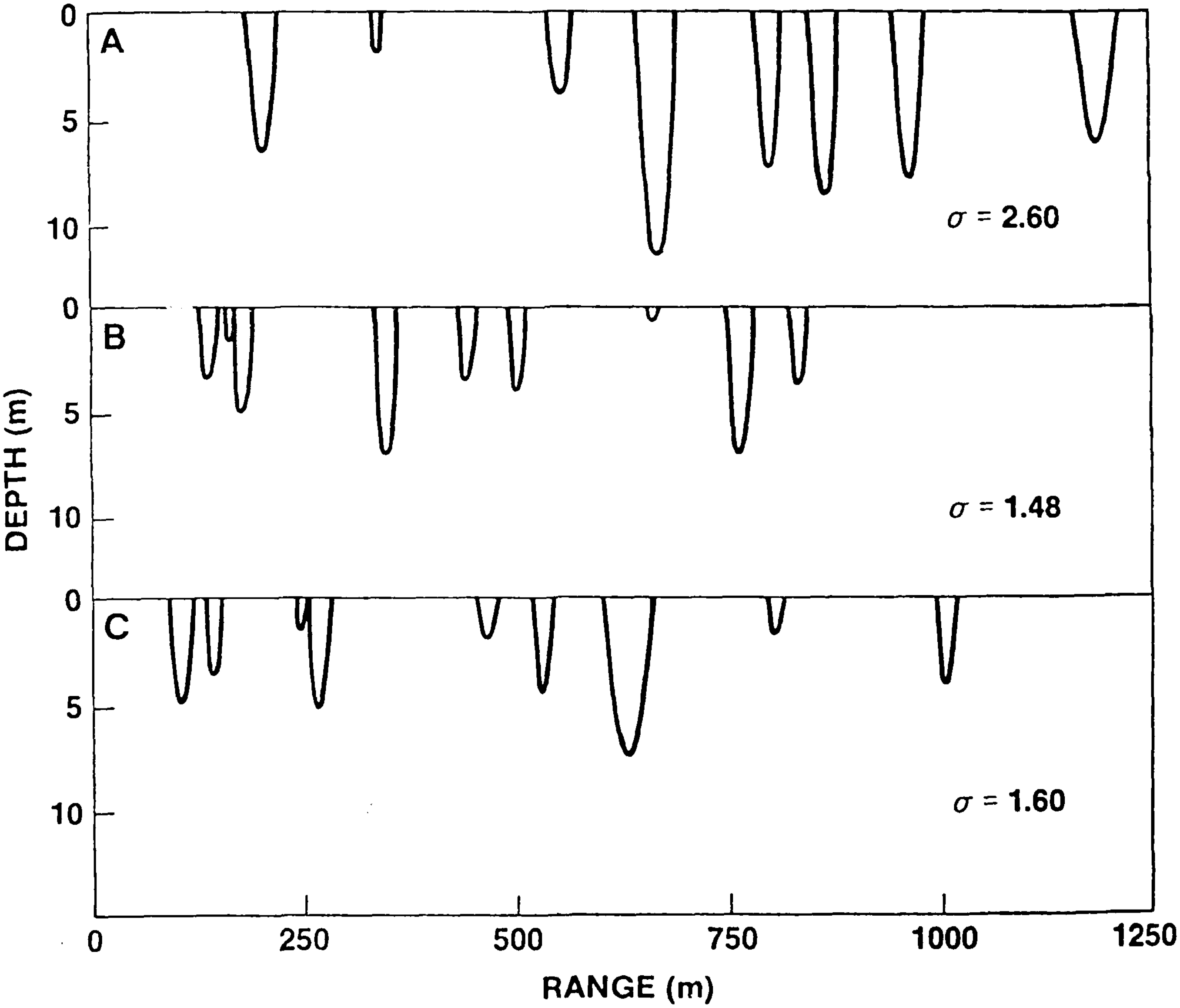
Three Random Ice Keel Sets



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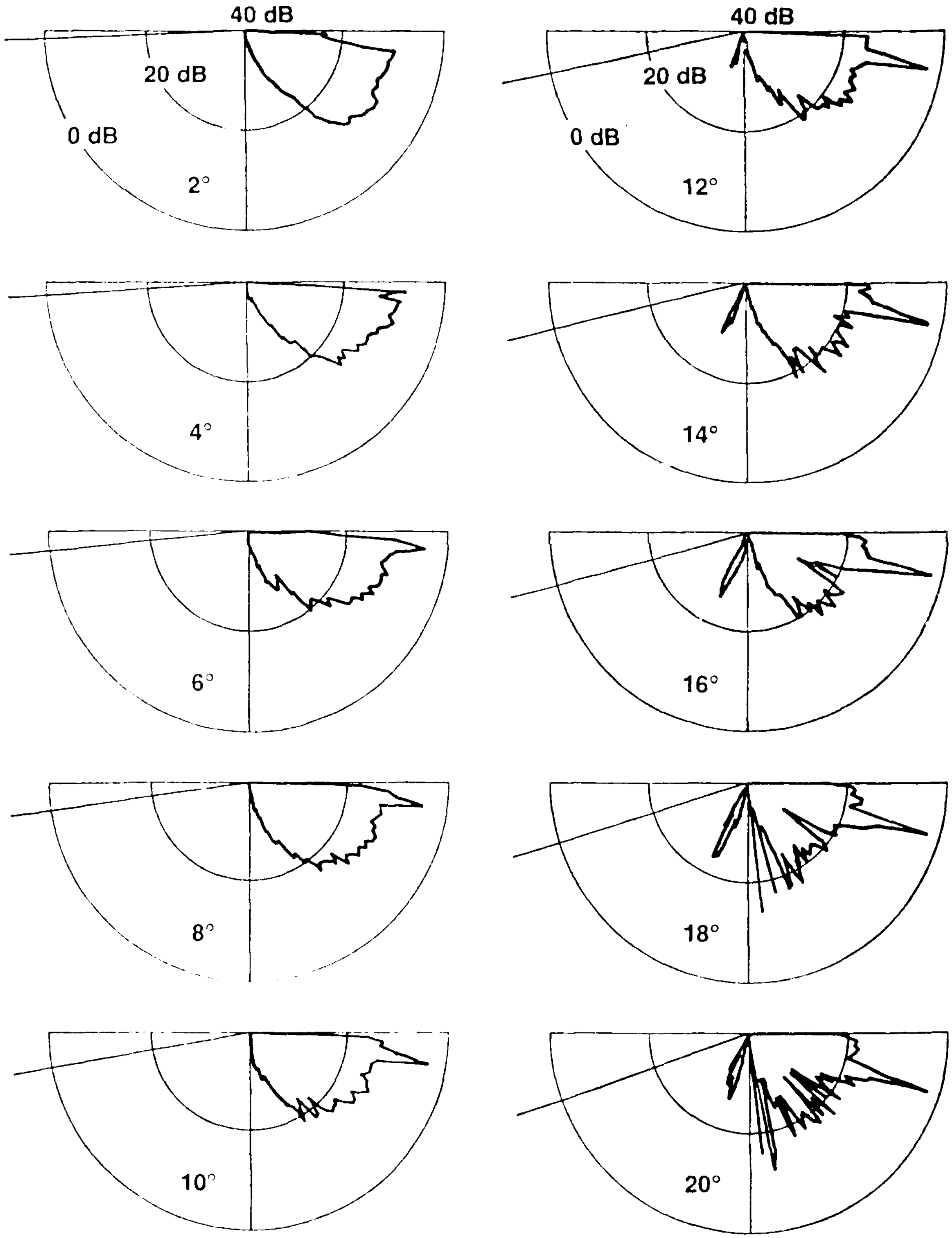
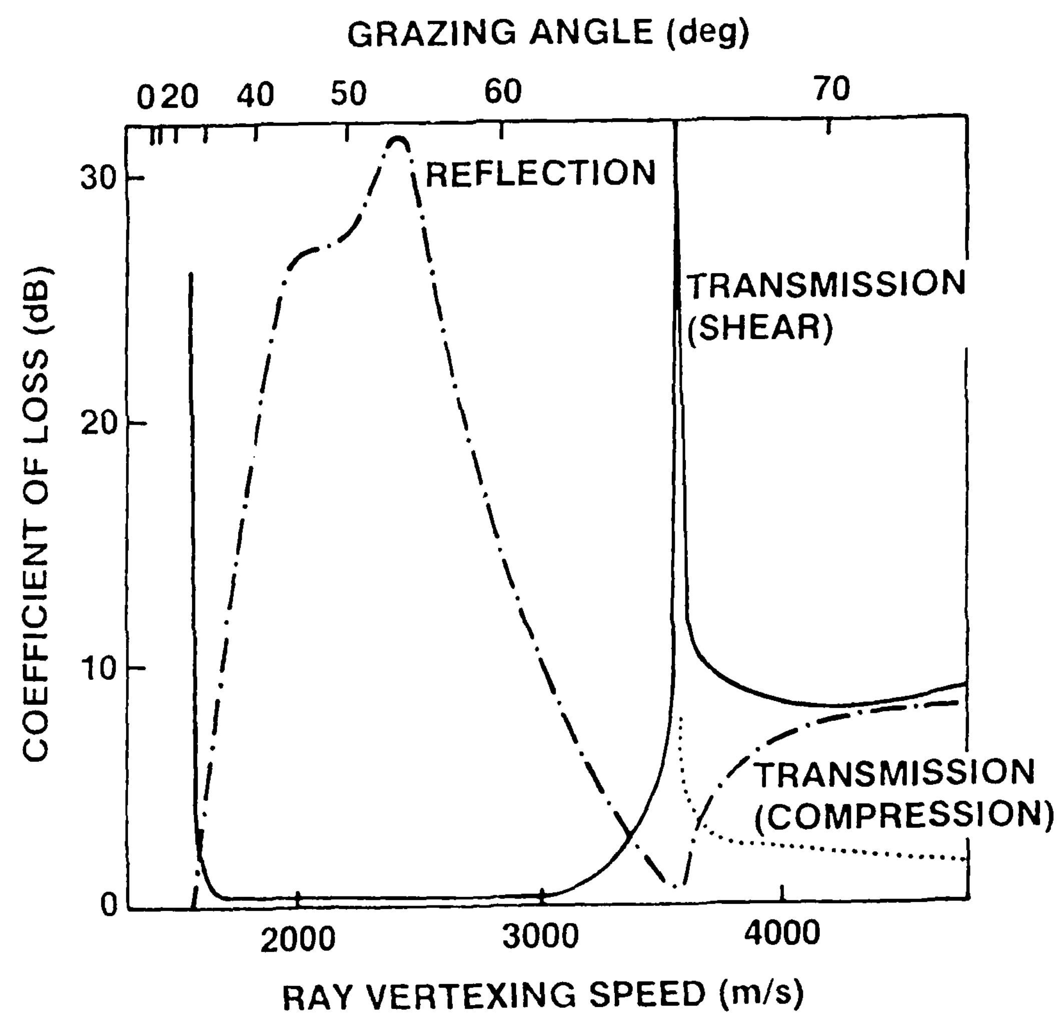
Directional Scattering Loss of Rays



Loss Coefficients for Reflection and Transmission



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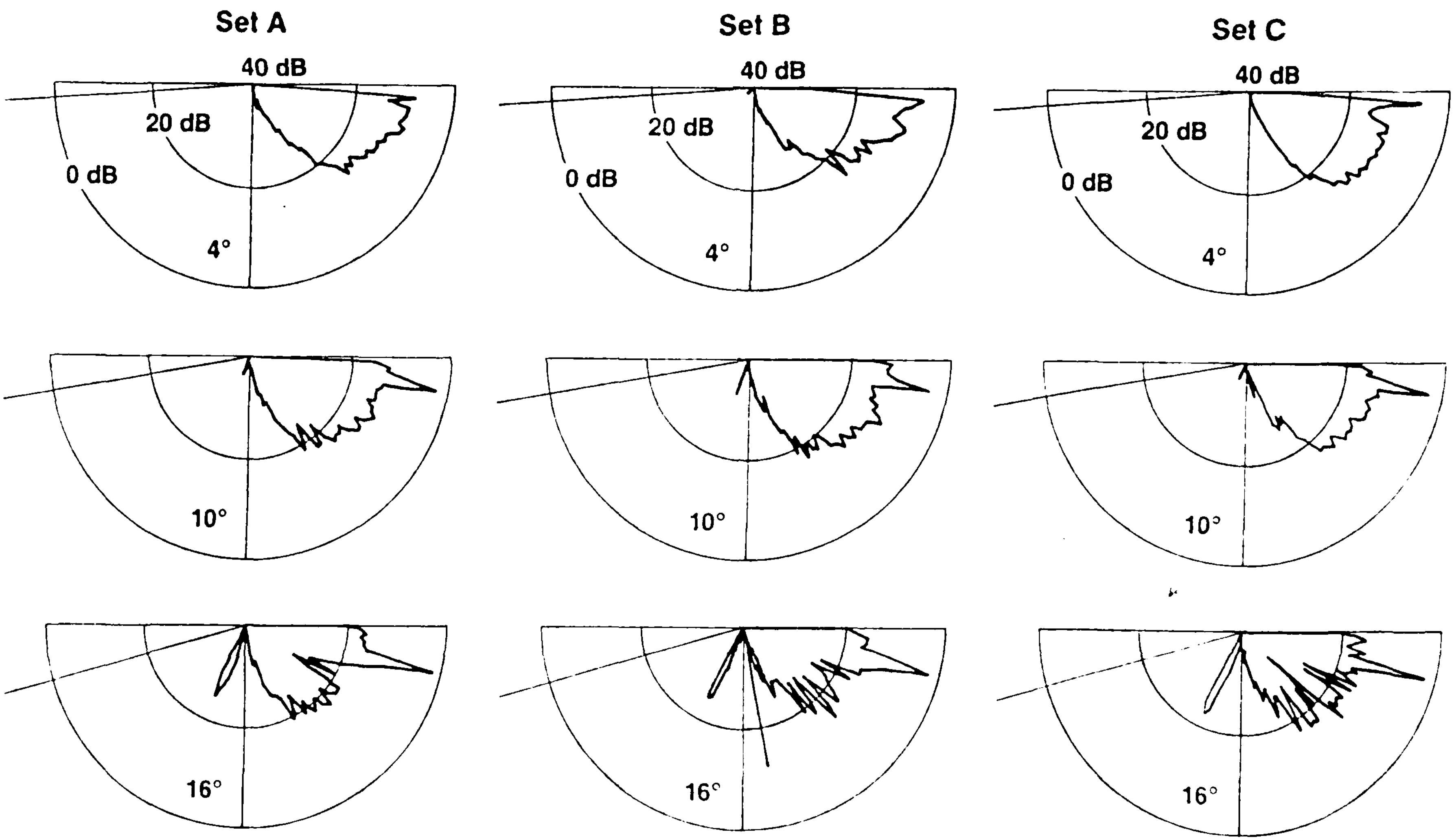
Directional Scattering Loss for Three Keel Sets



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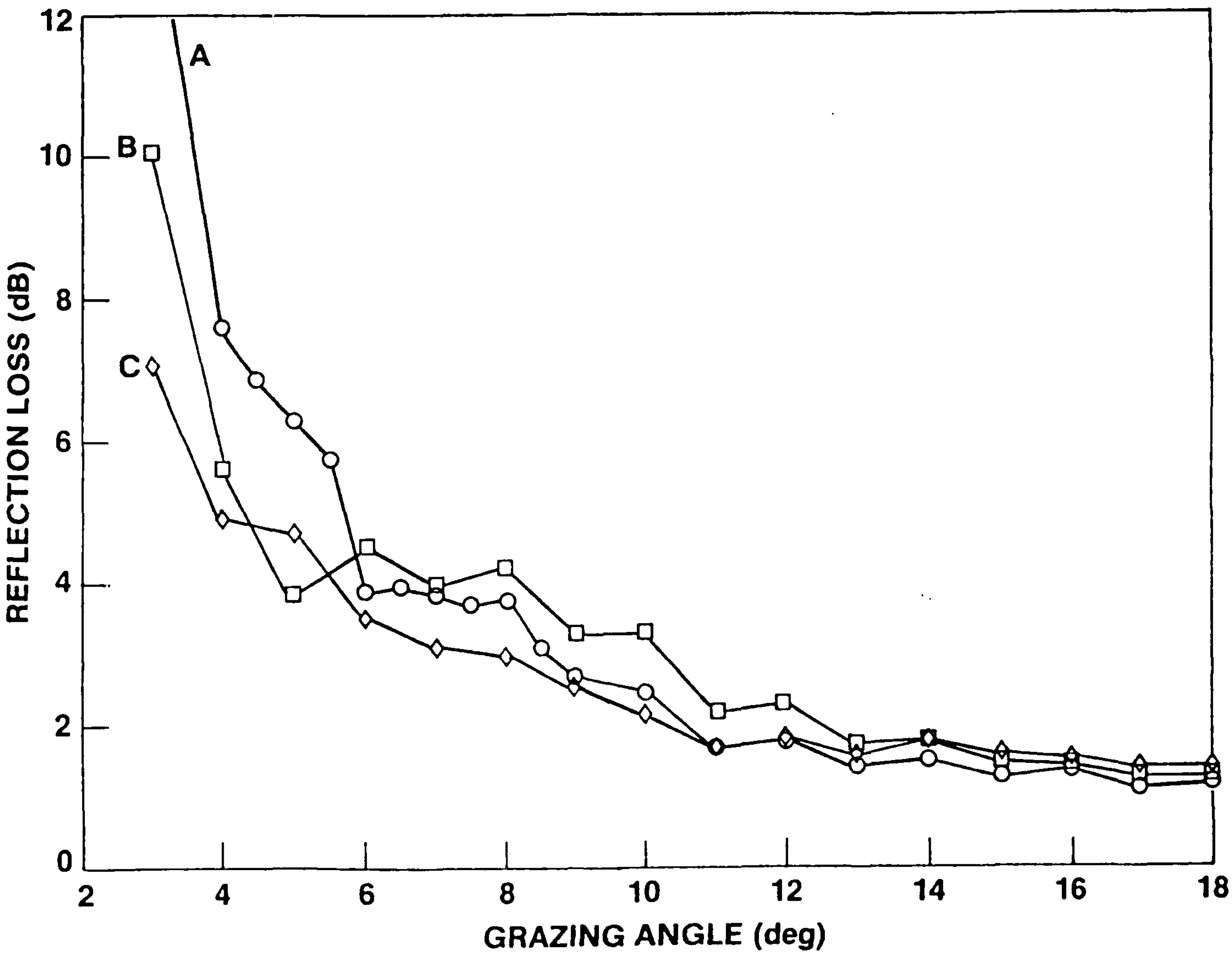
Specular Scattering Loss per Reflection



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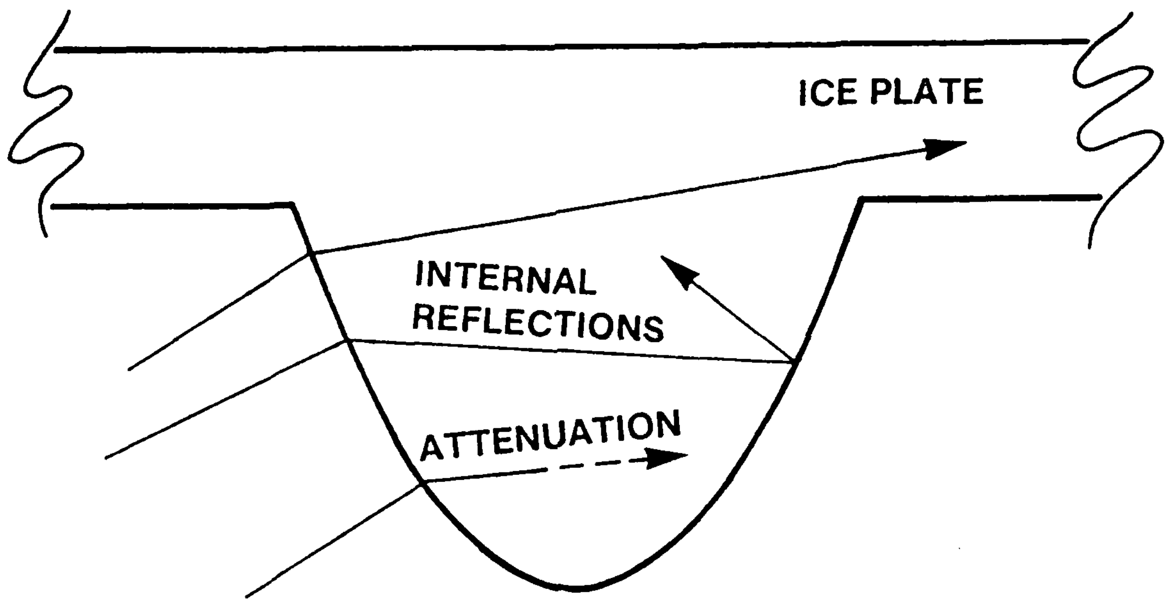
Deficiencies in the Model



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