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Modeling of Echoes From Elastic Spherical and Cylindrical Shells in a Convergence Zone

Presented at the 124th Meeting of the Acoustical Society of America, New Orleans, November 1992

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PREFACE

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MODELING OF ECHOES FROM ELASTIC SPHERICAL AND CYLINDRICAL SHELLS IN A CONVERGENCE ZONE

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TITLE SLIDE

The title of our talk is the "Modeling of Echoes from Elastic Spherical and Cylindrical Shells in a Convergence Zone."

OBJECTIVE

INTEGRATE TARGET AND ENVIRONMENTAL MODELS TO PRODUCE A NEW MODEL CAPABLE OF PREDICTING ECHOES FROM AN OBJECT IN A MEDIUM USING REALISTIC TRANSMITTED WAVEFORMS

SLIDE 1

Our objective was to integrate existing target and environmental models in order to produce the capability of predicting echoes from a target in an ocean environment using realistic transmitted waveforms.

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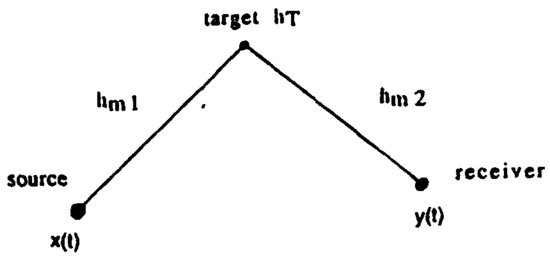
GENERAL FORMULATION



TOTAL IMPULSE RESPONSE $h(t) = h_{m1}(t) * h_T(t) * h_{m2}(t)$

$$y(t) = \int h(\tau)x(t-\tau)\,d\tau$$

$$= h(t) * x(t)$$

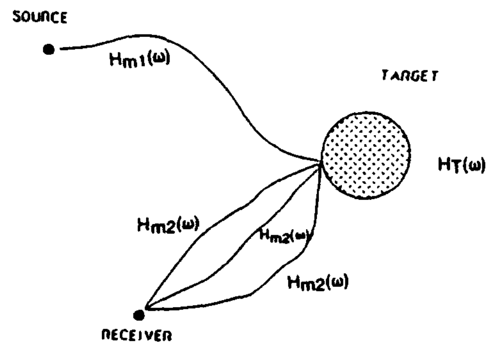
TIME SERIES = CONVOLUTION OF IMPULSE RESPONSE OF TARGET-MEDIUM SYSTEM *WITH INCIDENT SIGNAL*

SLIDE 2

The general formulation is as follows. We have a source transmitting the incident signal x(t), a target located at some range from the source and a receiver. Given x(t), we would like to predict the measured received signal y(t).

It is assumed that the total impulse response of the target-medium system is given by the convolution of the individual impulse responses. For the case depicted here, the total impulse response is equal to the convolution of the impulse response of the medium, for the source to target path, $h_{m1}(t)$, with the impulse response of the target, $h_T(t)$, convolved with the impulse response of the medium path from the target to the receiver position, $h_{m2}(t)$. Once h(t), the total impulse response, is obtained, we are able to find y(t), our desired echo, by convolving h(t) with our known incident signal x(t).

REPRESENTATION IN FREQUENCY DOMAIN



TOTAL TARGET-MEDIUM TRANSFER FUNCTION $H(\omega) = \int h(t)\, e^{i\omega t} dt$

$$= H_{m1}(\omega) H_T(\omega) H_{m2}(\omega)$$

$$y(t) = \int H(\omega) S(\omega) e^{-i\omega t} d\omega$$

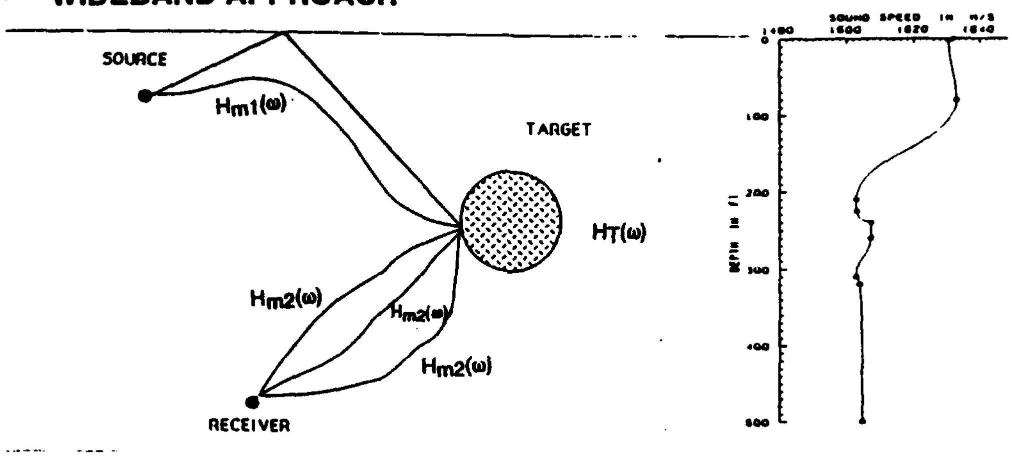
FREQUENCY REPRESENTATION OF SIGNAL $S(\omega) = \int x(t) e^{+i\omega t} dt$

SLIDE 3

In the frequency domain, where our model is implemented, the impulse responses become the transfer functions. A schematic drawing is shown here. We have the source, target and receiver positions with paths from the source to the target and from the target to the receiver. Many paths exist from the source to the target and from the target to the receiver. Only one source-target path and three target-receiver paths are shown for simplicity. The total transfer function, $H(\omega)$, is given by the product of the individual transfer functions, since convolution in the time domain corresponds to multiplication in the frequency domain. For the total target-medium system the transfer function $H(\omega)$ is given by the product of the transfer function of the source-target medium, $H_{m1}(\omega)$, the target transfer function $H_T(\omega)$ and the target-receiver medium transfer function $H_{m2}(\omega)$. Since we know our incident signal, $x(t)$, we can find its frequency representation $S(\omega)$. Our desired echo, $y(t)$, can now be found by multiplying the total transfer function $H(\omega)$ with the frequency representation of the incident signal $S(\omega)$ and taking the inverse Fourier transform.

TOTAL TRANSFER FUNCTION

- INCORPORATES RESPONSE OF TARGET AND MEDIUM
- OBTAINED USING THE GENERIC SONAR MODEL (GSM) AND A TARGET COMPONENT MODEL
- GSM: USES ACTUAL SOUND SPEED PROFILES, WINDSPEED, SOURCE AND RECEIVER LOCATIONS TO REALISTICALLY MODEL ENVIRONMENT
  - GSM: GIVES SOLUTION OF WAVE EQUATION THAT CAN BE INTERPRETED IN A RAY THEORETIC MANNER
- TARGET TRANSFER FUNCTIONS GENERATED USING EXPRESSIONS FROM "SOUND, STRUCTURES AND THEIR INTERACTIONS" BY JUNGER AND FEIT
- WIDEBAND APPROACH



SLIDE 4

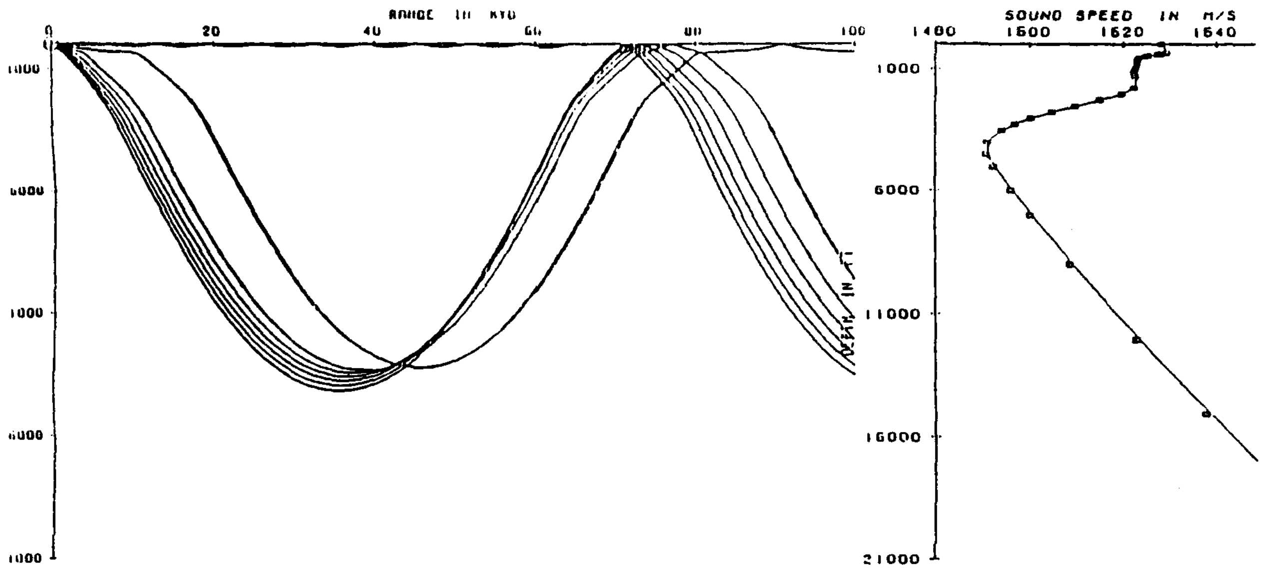
It is clear that once we have the total transfer function, we are able to obtain the echo, or time series, for any incident signal. The total transfer function incorporates both the response of the target and of the medium. In order to compute the source-target and target-receiver medium transfer functions, we utilize the Generic Sonar Model (GSM). GSM was developed at the Naval Undersea Warfare Center in the seventies. While not a ray model, GSM gives the solution of the wave equation in a form that can be interpreted in a ray theoretic manner. GSM inputs include sound speed profiles, windspeed and wave height information, bottom loss, source, receiver and target locations. GSM outputs information in eigenray files. These eigenray files contain amplitude, phase and time delay information for all the paths from the source to target and target to receiver. Also contained in the eigenray files are the angles at which the individual eigenrays leave the source and arrive at the target, and the angles at which the eigenrays leave the target and arrive at the receiver.

The target model currently consists of an elastic spherical shell and an elastic cylindrical shell. The target transfer functions are generated by using the thin shell theory found in Junger and Feit's "Sound, Structures and Their Interaction."

A schematic drawing of a source-target-receiver geometry is shown here. The arrangement is bistatic; however, the results shown will be for the monostatic case, with the source and receiver collocated. A GSM generated plot of the sound speed profile is shown to the right, with depth along the minus y direction, and sound speed along the x direction. Within the medium depicted, energy leaves the source and arrives at the target. GSM gives the eigenray information about the amplitude, phase and time delay of each of the paths. GSM also keeps track of the number of surface and bottom bounces the ray makes when traveling from the source to the target. The GSM eigenray angle information is important, since it is needed to determine the target response when using the shell equations from Junger and Feit.

CONVERGENCE ZONE CONDITIONS

Target Depth = 50 ft, Source Depth = 18 ft, Angles = +/- 5 deg



SLIDE 5

I will now move onto examples of the application of the model. Shown here are the sound velocity profile and corresponding ray trace generated by GSM. This is a convergence zone environment, with the convergence zone extending to about 80 kyards. The source to target range is 68 kyards, with the source at a depth of 18 feet and the target at a depth of 50 feet. Notice the duct that exists near the surface.

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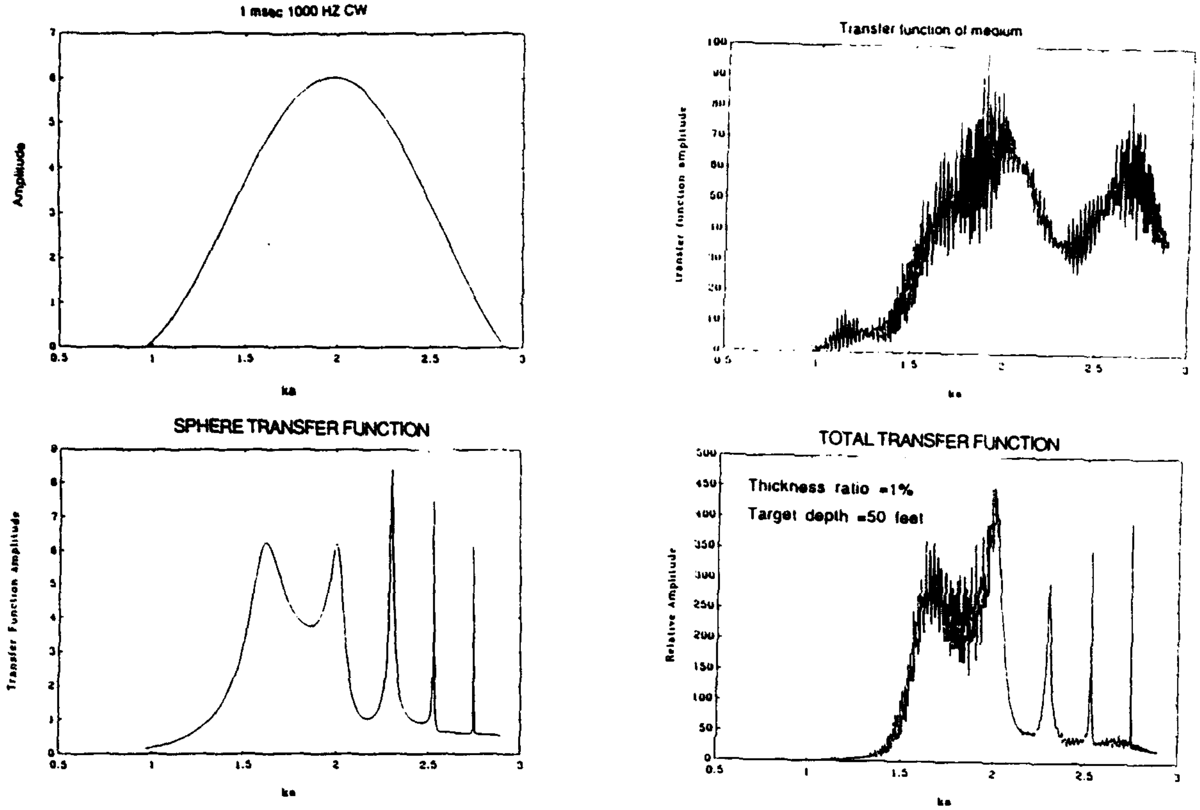
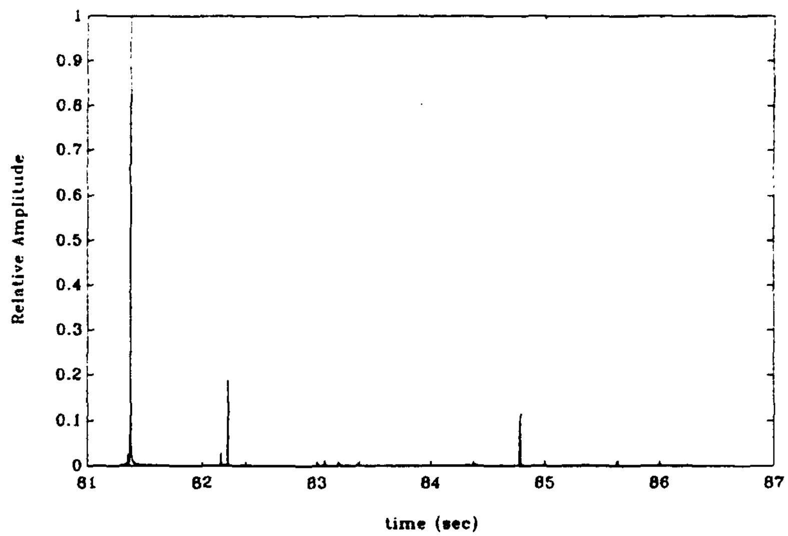


SLIDE 6

In the first example, the frequency representation of the 1 msec 1000Hz CW incident signal is shown. Beside it in the upper right corner is the transfer function of the medium as given by GSM. In the lower left hand corner, the transfer function of the spherical steel shell of radius .5 m and thickness ratio 1% that will be used as a target is depicted. In the last figure, the total target-medium transfer function is shown. One can see the contributions of both the target and the medium to the total transfer function. The peaks that occurred in the target transfer function also appear in the total transfer function. The medium produces the rapid oscillations in the medium-alone transfer function and the total transfer function.

ECHO FROM MEDIUM
50 FT TARGET DEPTH



SLIDE 7

The echo from the medium alone is computed using the frequency representation of the incident signal and the medium transfer function. The inverse FFT produces the time series for the medium shown here. The peaks are due to the multipath arrivals. This example uses the 50-foot target depth.

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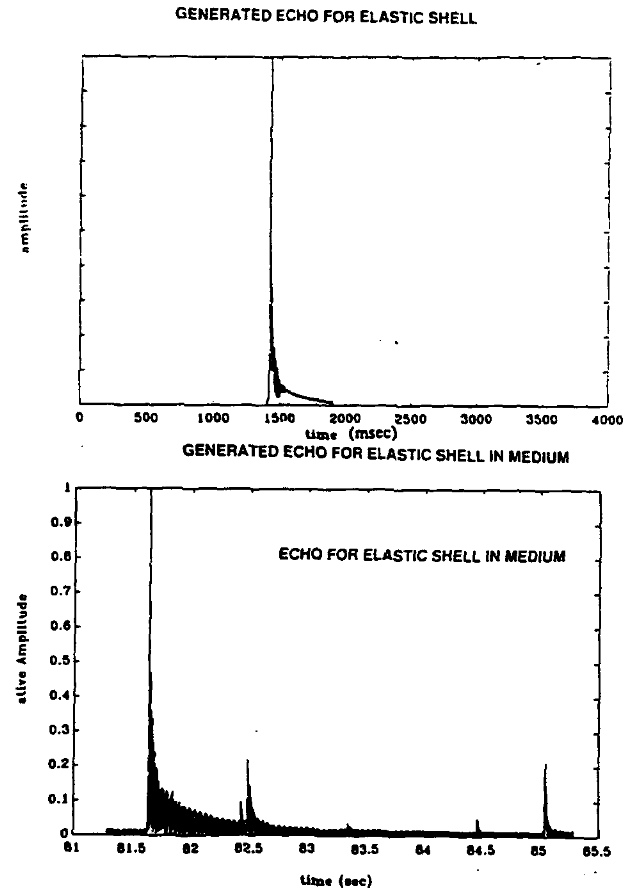
ECHO FROM STEEL SPHERICAL SHELL
1 MSEC 1000 HZ CW INCIDENT SIGNAL



SLIDE 8

Multiplying the total transfer function with the frequency representation of the incident signal and taking the inverse Fourier transform produces the echo time series for the object in the medium. The echo is shown in the bottom figure. The upper figure is the echo for the elastic spherical shell without the medium; that is, using a straight path to and from the target. The multiple peaks in the target-medium echo are due to the multipaths present in the medium response. Note that the total target-medium echo peaks incorporate the ringing seen in the peaks in the target-alone echo.

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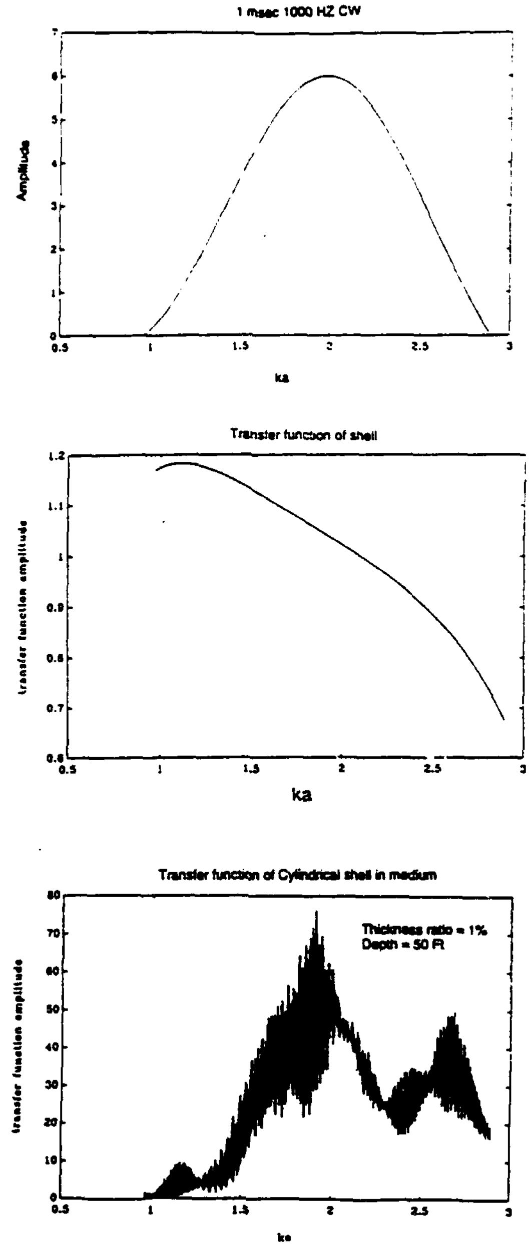

SLIDE 9

The next example uses the same input signal, but has an infinite steel cylindrical shell with thickness ratio 1% as a target. The medium response is the same as in the previous example since the target depth is the same. The transfer function of the cylindrical shell is a very smooth function over this frequency range and has no sharp peaks. The total target-medium transfer function is shown in the bottom figure. It closely resembles the response of the medium alone due to the smoothness of the target transfer function. Since the cylinder transfer function is decreasing over the frequency range, the total response at the higher end of the frequency band is smaller in amplitude than the medium alone response.

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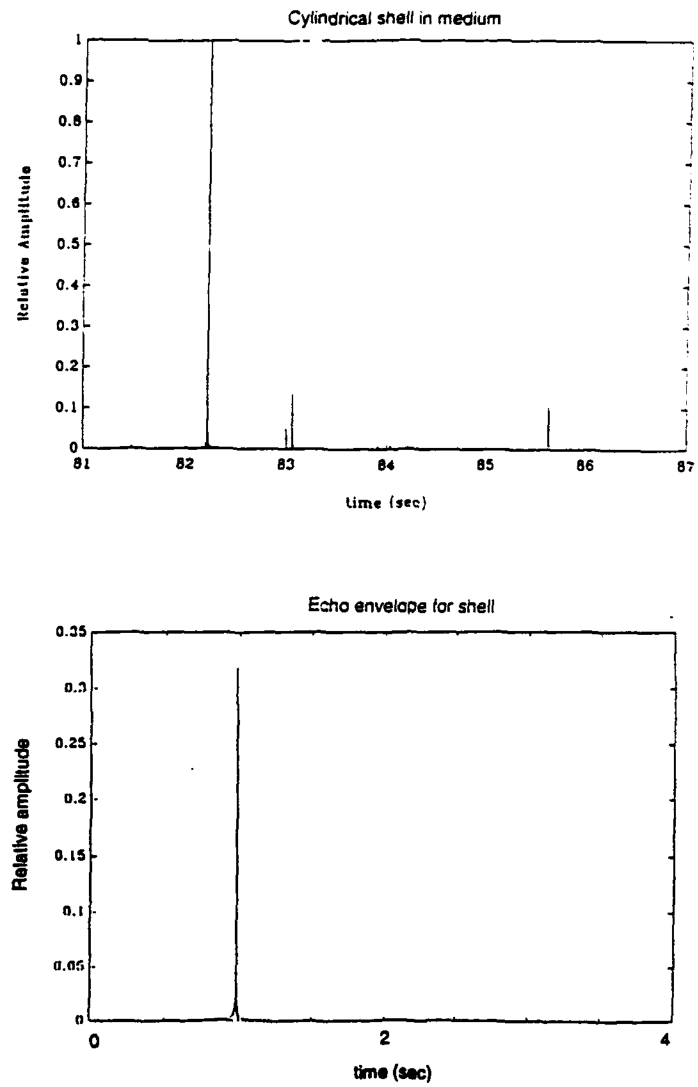
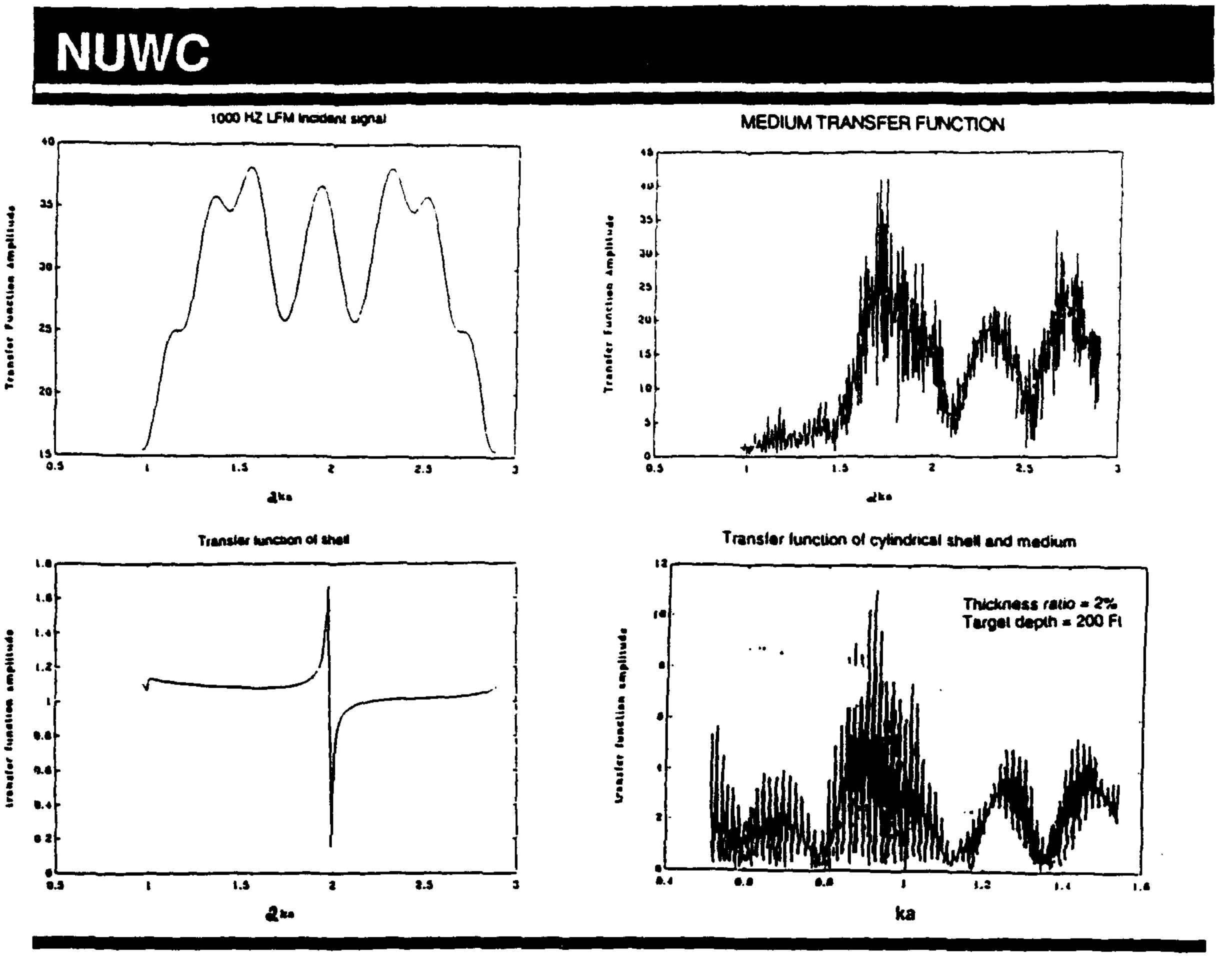
ECHO FROM INFINITE STEEL CYLINDRICAL SHELL
1 MSEC 1000 HZ CW INCIDENT SIGNAL



SLIDE 10

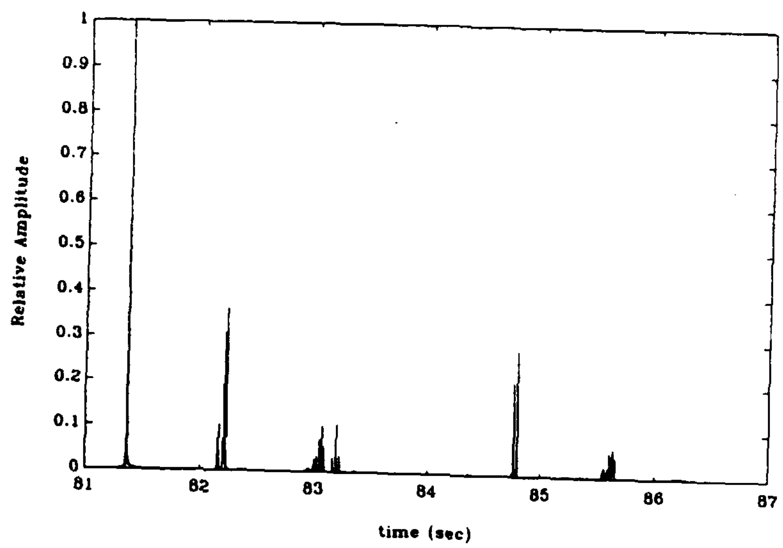
The echoes produced using the incident signal and the total target-medium transfer function and the transfer function of the steel cylindrical shell alone are shown here. Since the shell transfer function was so well behaved, the echo from the shell without the medium, in the lower figure, does not show a ringing as was seen with the spherical shell. The full echo response, shown in the upper figure, has many peaks due to the multipath arrivals. Since there were no resonances for the target in this example, the peaks do not display a tail.



SLIDE 11

The last example uses an LFM incident signal with a 1000 Hz bandwidth. The frequency representation of the signal is shown in the top figure. A plastic cylindrical shell with a thickness ratio of 2% and a radius of .25m is used as a target. Its transfer function is shown in the lower left corner, plotted against twice the ka values. The target has a sharp response near a ka of 1, which is shown on the plot at a value of 2ka=2. The target is placed at a depth of 200 feet. The medium response for this new target location is shown in the figure in the upper right. Finally, the total transfer function is computed and shown in the last figure.

ECHO FROM MEDIUM
200 FT TARGET DEPTH



SLIDE 12

The medium-alone echo for this target depth position at 200 feet is shown in this figure. The peaks display the presence of more multipaths than in the previous example with a more shallow target position.

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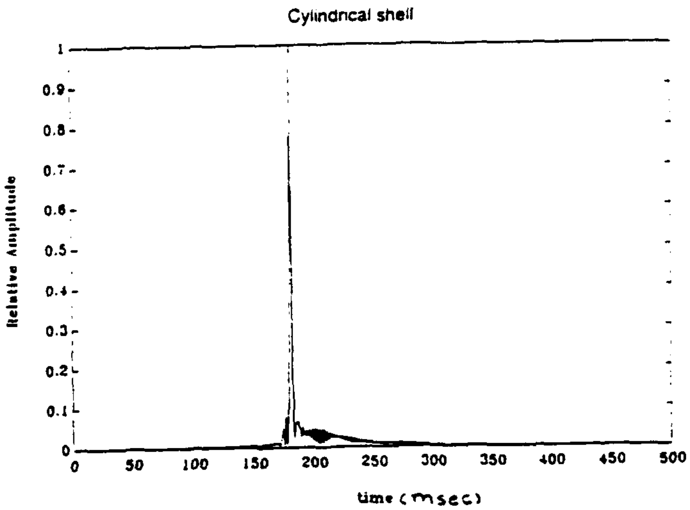
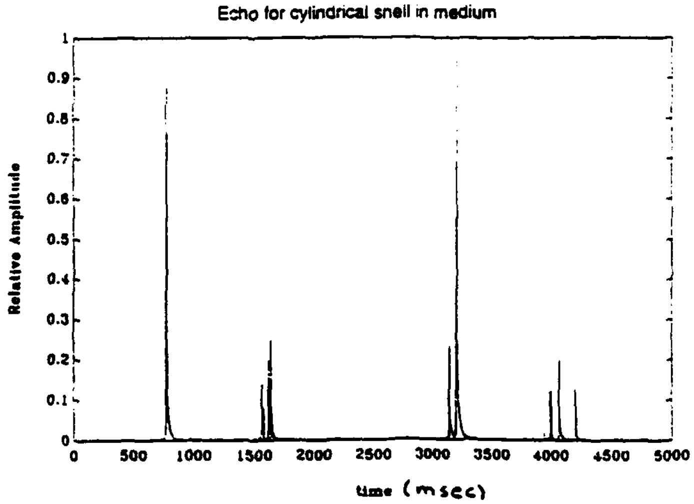
ECHO FROM INFINITE PLASTIC CYLINDRICAL SHELL
LFM INCIDENT SIGNAL





SLIDE 13

Using the LFM and the plastic shell alone produced the echo shown here in the top figure. Notice that there are oscillations following the peak due to the rapid fluctuation of values in the traget response near ka = 1. The echo for the target in the medium is shown below. Again, the multiple peaks are due to the multipaths present in the medium. After each peak, there is an extension, or tail, that is due to the presence of the target.

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SUMMARY

- DEVELOPED CAPABILITY OF GENERATING ECHOES FROM SPHERICAL AND CYLINDRICAL SHELLS FOR AN ARBITRARY INCIDENT SIGNAL IN AN ACOUSTIC MEDIUM.
- COMBINED ENVIRONMENTAL MODEL (GSM) MULTIPATH INFORMATION WITH TARGET RESPONSE.
- FUTURE WORK: COMPARISON WITH DATA; OBTAIN ABSOLUTE ECHO LEVELS; OTHER ENVIRONMENTS.

SLIDE 14

In summary, we have developed the capability of generating echoes from spherical and cylindrical shells for an arbitrary signal in an acoustic medium. This was accomplished by combining the GSM multipath information with a target response given by equations in Junger and Feit, using the convolution model assumption. Future work includes normalizations to compare results with data and applications of the method to other environments.

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